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# Energy performance assessment of passive buildings in future climatic scenarios: the case of study of the childcare centre in Putignano (Bari, Italy)

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**Abstract.** The building sector is a primary target for GreenHouse Gas emissions mitigation efforts, as it accounts for 36% of final energy use. The most effective mitigation strategies include the energy retrofit of the existing building stock. Among existing buildings, particular attention should be paid to school buildings, which are among the most diffuse public buildings in Europe, most of them built decades ago, with a resulting high potential in terms of refurbishment effectiveness. Moreover, schools cover a social function and require high levels of indoor environmental quality. In this field, the research activity is intense, but retrofit strategies are still conceived considering historical weather data, which could not represent correctly present and future climate patterns, reducing the retrofit effectiveness. In this work, an energy retrofit to “Passivhaus standard” of a childcare centre located in the Mediterranean area is analysed through dynamic simulations. A post-retrofit building model is simulated using Typical Meteorological Year (TMY) and compared with the ones simulated in future weather scenarios, created using the morphing method. The analyses aim to assess if the technical solutions currently adopted on the basis of the TMY will lead to acceptable energy performance in future decades. Furthermore, a sensitivity analysis of different design solutions is performed, aiming to assess their effectiveness in future weather conditions.

## 1. Introduction

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia [1]. The Mediterranean region is likely to warm at a rate about 20% larger than the global annual mean surface temperature. Day temperatures are likely to increase more than night temperatures and summers more than winters leading to an increase of amplitude of both daily and annual temperature range [2].

The building sector will be a primary target for GreenHouse Gas (GHG) emissions mitigation efforts, as it accounts for 36% of final energy use and 39% of energy and process-related emissions [3]. The most diffuse and effective mitigation strategies include the construction of nearly zero energy buildings (nZEBs) and the energy retrofit of the existing building stock. At the same time, the ability to adapt to the adverse impacts of climate change is required for all buildings [4], because climate change impacts will continue for centuries, regardless the efforts to reduce anthropogenic emissions of greenhouse gases [1].



Among existing buildings, particular attention should be paid to educational buildings, for several reasons. Schools are among the most diffuse public buildings in Europe, most of them were built decades ago, with a resulting high potential in terms of refurbishment effectiveness. Moreover, schools cover a social function and require high levels of indoor environmental quality. In this field, the research activity is intense, but retrofit strategies are still conceived considering historical weather data, which could not represent correctly present and future climate patterns, thus reducing the retrofit effectiveness.

Studies on the impact of climate change on building energy consumptions in the different areas of the world are widespread, showing a decrease in heating energy use and an increase in cooling energy use in Mediterranean climate [5]. The literature available on climate implication and adaptation measures for buildings is accurately summarised by Stagrum et al. in a scoping review, showing the current state of art in this field and the most important research gaps [6]. The authors find a relatively limited literature compared with the scale of the topic, highlighting the need of further research. For instance, most of the studies focus on residential and commercial buildings, characterised by constant occupation during the whole year. On the contrary, educational buildings show a discontinuous occupancy, due to the summer closure period which is, moreover, the most affected by climate change. In addition, schools are characterised by high internal loads due to the level of occupation that can reach up to four times the offices occupancy rate [7], leading to an increased risk of overheating [8]. This may affect the energy consumptions, highlighting an increasing need of further investigation.

As previously mentioned, educational buildings need to be retrofitted, because of their age, maintenance needs, and their influence in the learning performance of the students [9]. Saving energy with cost effective solutions is the primary target for schools retrofit design, whereas the improvement of indoor environmental comfort should also be considered. The Passive House approach, among many available standards used in building retrofit, is undergoing a rapid expansion in the last few years, also in the non-residential sector. Although this standard guarantees a low energy consumption and high levels of indoor comfort in the current climate, the effectiveness of these solutions needs to be verified in both current and future weather scenarios.

This paper aims to assess the effectiveness of an energy retrofit design according to the Passivhaus Standard [10] on a case study of a childcare centre in the Mediterranean region, in three future weather scenarios. The main reason is to better understand if the adopted standard can represent a resilient solution for future climate conditions, or if some further modifications on specific strategies are required. Furthermore, a sensitivity analysis of different design solutions is performed to evaluate their potential in energy savings in a changing climate.

## 2. Case study

A childcare centre located in Putignano (40°51'3 N, 17°7'18 E), 40 km far from the city of Bari in Southern Italy, was used as case study. It was built in 1960s and designed to be used as school since its construction. The school accommodates 207 children ranging from 3 to 6 years old. The building has a complex shape, with a gross floor area of 1600m<sup>2</sup>, divided in two floors, and a shape factor equal to 0.94m<sup>2</sup>/m<sup>3</sup>. The main sides are facing north-east and south-west. The school consists of nine classrooms, two large rooms for children activities and service areas. Each classroom has large windows, without any solar shadings (figure 1, right). The existing building is made of non-insulated masonry envelope thus a retrofit design in accordance with the Passivhaus standard has been proposed.



**Figure 1.** Floor plan of the first floor with thermal zones(left); external view of two classrooms(right).

### 3. Methodology

The methodology adopted in this research consists of three main steps: the generation of the future weather files, the realization of the building energy models, and the sensitivity analysis.

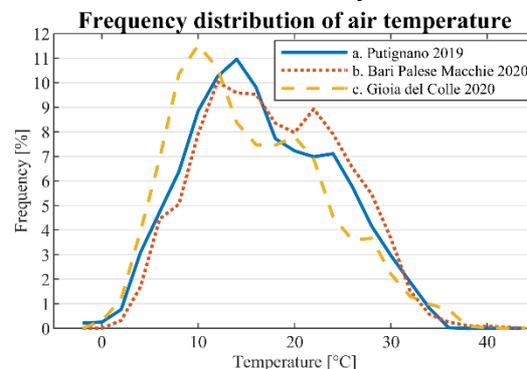
#### 3.1. Generating future weather files for Building Performance Simulations (BPS)

In order to assess building energy performances under the future weather scenarios, future weather data in a BPS readable format are required.

Future weather files were created by adopting the approach presented by Jentsch et al. [11], who developed the tool CCWorldWeatherGen. It provides hourly future weather data, applying the morphing method [12], using HadCM3 (Hadley Centre Coupled Model, version 3) forced with IPCC A2 emission scenario. The tool superimposes relative changes on the weather variables stored in Typical Meteorological Year (TMY), by applying three transforming functions: shifting, stretching and their combination. It allows to generate future weather files within three time slices: 2011-2040 ('2020s'), 2041-2070 ('2050s') and 2071-2100 ('2080s').

Since a TMY is not available for the town of Putignano, two current weather data files for two neighboring cities were considered to evaluate which one was more suitable to represent local conditions: a TMY for Bari Palese-Macchie (40 km far from Putignano) and a TMY for Gioia del Colle (20 km far from Putignano). These TMYs belong to the Italian Climatic data collection "Gianni de Giorgio" (IGDG) and derive from the observations collected in the period 1951-1970 [13]. Both the weather files were used as a baseline to create two future Energy Plus Weather files for 2020, and the resulting future hourly temperatures were compared with the ones recorded in Putignano in 2019.

As shown in figure 2, the EPW file of Bari-Palese Macchie was the most representative of the temperatures recorded in Putignano in 2019, therefore it was chosen as a baseline to create all the future weather files. Using the previous tool, the three future Energy Plus Weather files (EPW) were created (referred as 'Bari 2020', 'Bari 2050' and 'Bari 2080'), ready to use in BPS tool.



**Figure 2.** Frequency distribution of air temperature: (a) recorded in Putignano in 2019; (b) expected in Bari in 2020; (c) expected in Gioia del Colle in 2020.

Furthermore, the Heating Degree Days (HDD) [14] and the Cooling Degree Days (CDD) [15] were calculated and compared between the four scenarios, showing the shift towards warmer temperatures due to the climate change as described in the comparison illustrated in Table 1.

**Table 1.** Comparison of HDD and CDD for the four weather scenarios and percentage variation with respect to IGDG.

	IGDG	2020	2050	2080
HDD <sub>20°C</sub> [°Cxdays]	1409	1326	1162	976
Variation with respect to IGDG	-	-6%	-18%	-31%
CDD <sub>24°C</sub> [°Cxdays]	142	223	367	576
Variation with respect to IGDG	-	+57%	+158%	+306%

As shown in Table 1, the global warming leads to a large increase of CDD compared to the reduction of HDD, and thus influences the global energy consumption of buildings.

### 3.2. Building energy performance simulation models

Nine energy models of the case study were created using Design Builder software [16] to evaluate and compare the building energy performances under current and future weather scenarios (Bari 2020, Bari 2050, Bari 2080).

Firstly, an energy model in accordance with the 'reference building' required by the Italian law [17] was created (model 0) and simulated both in the current and future conditions. After that, it was used as a baseline to perform a sensitivity analysis, aimed at assessing the effectiveness of different design solutions in future weather conditions, based on the minimisation of total energy consumption. The performed analysis belongs to the class of the one-factor-at-time methods; therefore, six different models were created and, in each model, one input factor was changed, while all the other factors were fixed (models 1,2,3,4,5,6). The single input variable evaluated, and their range of variation are summarized in the Table 2. Afterward, on the basis of the results of the sensitivity analysis, the optimal value of each of the six changing factors was selected and used as input to build the 'optimised model' (model 7). Both the reference model and the optimised one were simulated in the current and future weather scenarios and compared with a further energy model created according to the 'Passivhaus standard' (model 8).

The input parameters to perform dynamic simulations for the model 0 and the model 8 are illustrated in Table 3, whereas the ones for the model 7 are presented in the results paragraph. The simulations were carried out adding to the models an ideal active system, with a COP equals to 3.5 for heating and equals to 2.5 for cooling. The heating period was set from 7a.m. to 5p.m. from 1° November to 15 April [17] and the heating set-point temperature set on 20°C. The cooling set-point temperature was set on 24°C, according to [18] and the cooling period was set from 1° May to 15 October, because no constraints are provided by the Italian law. A mechanical ventilation system with a recovery efficiency of 0.70 was considered in each zone, with an air flow rates of 5 l/s per person [19]. Furthermore, the discontinuous occupancy of the school was taken into account: the building was considered occupied during weekdays from 8a.m. to 16p.m., on Saturdays from 8a.m. to 1p.m., and closed during all national holydays, on Sundays, and during July and August. Seven thermal zones were created, according to the use of each room: 9 classrooms, 2 playrooms, 1 school canteen, and toilets, storerooms, corridors, and a food preparation area.

**Table 2.** Input variables and their range of variation for the sensitivity analysis.

Model	Input variable	Units of measure	Variation range
1	External wall thermal transmittance	W/m <sup>2</sup> K	0.29-0.159
2	Roof thermal transmittance	W/m <sup>2</sup> K	0.26-0.169
3	Floor (facing the ground) thermal transmittance	W/m <sup>2</sup> K	0.29-0.16
4	External window thermal transmittance	W/m <sup>2</sup> K	1.8-1
5	SHGC	-	0.35-0.26
6	Solar shading thickness	cm	50-140

**Table 3.** Input parameters for dynamic simulations: (0) reference building; (8) Passivhaus building.

Input parameters	Units of measure	Model 0	Model 8
<b>Building</b>			
Thermal conditioned area	m <sup>2</sup>		1219
Numbers of floors	n.		2
Shape factor	m <sup>2</sup> /m <sup>3</sup>		0.94
Occupancy	Children + staff		234
Windows-to-wall ratio	%		13.96
<b>Envelope</b>			
Roof thermal transmittance	W/m <sup>2</sup> K	0.26	0.186
External wall thermal transmittance	W/m <sup>2</sup> K	0.29	0.176-0.179
External window thermal transmittance	W/m <sup>2</sup> K	1.8	1.2
Slab to ground thermal transmittance	W/m <sup>2</sup> K	0.29	0.25
Floor (facing unheated space) thermal transmittance	W/m <sup>2</sup> K	0.29	0.26
Solar shading thickness	cm	50	100

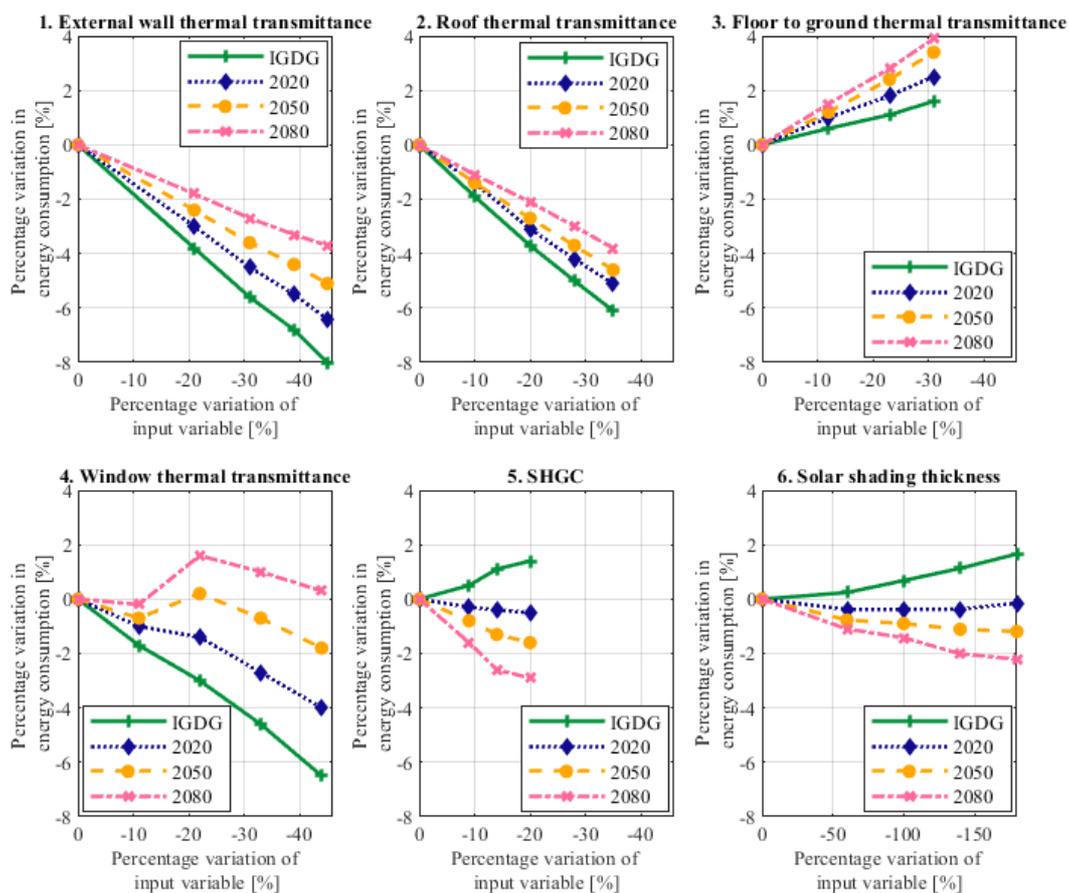
#### 4. Results and discussion

Hereafter are presented the main results on the assessment of the impact of the future weather scenarios on the building energy demand and on the evaluation of different design solutions in future weather conditions. The first subparagraph gives the results of the sensitivity analysis, whereas the energy performances of the three main models (models 0,7,8) are analysed and compared in the second subparagraph.

##### 4.1. Sensitivity analysis

In order to investigate the effectiveness of different retrofit solutions on the reduction of building energy consumptions in the future weather scenarios, the sensitivity analysis was carried out, and the results are illustrated in Figure 3.

As shown, the graphs 1, 2, and 4 highlight that the reduction of thermal transmittance reduces progressively its effectiveness in all the future weather scenarios. Considering the graphs 5 and 6, the reduction of the SHGC and the increase in the solar shadings thickness leads to an increase in energy consumption with TMY weather file, whereas in the three future scenarios they are advantageous for improving energy savings. In conclusion, referring to the case 3, the reduction of thermal transmittance is not beneficial for the energy consumption, increasingly so with future climate. The increase or decrease of energy consumption is due to the balance between the reduction of heating and the increase of cooling, thus solutions based on winter period will become less effective in the future climate when summer conditions need to be taken into account.



**Figure 3.** One-factor-at-time sensitivity analysis for energy saving with respect to: model 1) external wall thermal transmittance; model 2) roof thermal transmittance; model 3) slab to ground thermal transmittance; model 4) window thermal transmittance; model 5) SHGC; model 6) solar shading thickness.

As previously said, the results of the sensitivity analysis allow to create an optimised model (7), by selecting the optimal value of the changing factors in each of the six models (1,2,3,4,5,6). This method is useful to analyse the effects of the combination of the best parameters on the energy consumption minimisation. Nevertheless, varying one factor at a time does not allow to identify the interaction between variables, that could be considerable. Therefore, the combination of the optimal input variables could not lead to the best solution for reducing consumption, thus requiring future studies.

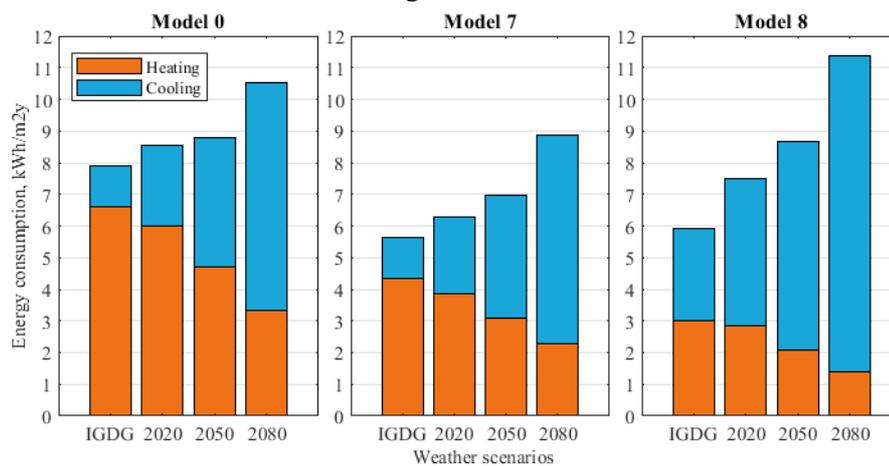
The chosen input values are presented in Table 4.

**Table 4.** Input parameters for dynamic simulation: optimised model (7).

Input variable	Units of measure	Value
External wall thermal transmittance	W/m <sup>2</sup> K	0.16
Roof thermal transmittance	W/m <sup>2</sup> K	0.17
Floor (facing the ground) thermal transmittance	W/m <sup>2</sup> K	0.29
External window thermal transmittance	W/m <sup>2</sup> K	1.0
SHGC	-	0.28
Solar shading thickness	cm	120

#### 4.2. Performance of the energy models under current and future weather scenarios

The yearly energy consumptions for heating and cooling for the building models 0, 7 and 8, under the four weather scenarios, are illustrated in Figure 4.



**Figure 4.** Yearly energy consumption for heating and cooling per unit of net floor area: model 0) reference building; model 7) optimised model; model 8) Passivhaus model.

As the figure shows, heating energy needs exceed cooling energy needs in all the models, under the current scenario, not only due to the current climatic conditions but also to the school closure period from July to August. Nevertheless, the figure shows that in the future weather scenarios, the heating energy needs are reduced, whereas the cooling needs increase for all models. Although the school has a long summer closure period, the magnitude of reduction in heating and the magnitude of increase in cooling are not comparable, resulting in an overall growth of the total building energy consumption, due to the large internal heat gains, mainly related to the occupancy rates. According to the literature, climate change leads to warmer temperatures during the whole year and leads to a shift in heating and cooling. Although this shift is found for all the models, the corresponding weather scenario is changing from a case to another. Indeed, in the model 8, cooling consumption overtakes heating consumption in the short term (2020), whilst in the model 0 the shift appears only in the long term (2080) and in the model 7 in the medium term (2050). Table 5 reports the yearly energy needs for the three models and their percentage variations compared to the IGDG scenario.

**Table 5.** Yearly energy consumption for heating and cooling under future weather scenarios and percentage variations based on the IGDG scenario: model 0) reference building; model 7) optimised model; model 8) Passivhaus model.

Energy consumption [kWh/m <sup>2</sup> y]	Weather scenario											
	IGDG			2020			2050			2080		
	0	7	8	0	7	8	0	7	8	0	7	8
Heating	6.6	4.4	3.0	5.98	3.9	2.83	4.69	3.11	2.09	3.34	2.27	1.38
Variation [%]				-9.6	-11.2	-6.4	-29	-29	-31	-50	-48	-55
Cooling	1.3	1.3	2.9	2.58	2.4	4.67	4.16	3.87	6.56	7.18	6.58	9.98
Variation [%]				+100	+92	+62.3	+224	+204	+128	+460	+417	+247
Heating + cooling	7.9	5.6	5.9	8.56	6.3	7.5	8.86	6.98	8.65	10.52	8.85	11.35
Variation [%]				+8.4	+12.2	+27.1	+12.2	+24	+47	+33	+57	+92

Considering the energy consumption in absolute terms, the optimised model 7 has the lowest consumption in all scenarios. Comparing the models 0 and 8, the models 8 has lower consumption in the current condition and in 2020, comparable consumption in 2050, but higher consumption in 2080. Nevertheless, the magnitude of variation in heating and cooling due to climate change is substantially different among the models. The model 8, representing the Passivhaus school, has the highest percentage increase in energy consumption, due to a large increase of cooling demand, in all the future weather scenario. This result depends on the high level of insulation of the retrofitted building. On the contrary, the model 0 has the lowest percentage increase, due to its lower levels of insulation, providing better performance in summer conditions.

Overall, although insulation is still advantageous in reducing cooling energy, its effectiveness compared to the heating is reduced, because the difference between indoor and outdoor temperatures is lower. It is worth noting that this distance will decrease in the future scenarios, due to the load elements which contribute to the thermal balance. Indeed, while the internal heat gains (equipment, occupancy, general lighting, and catering) are unchanged in future conditions, solar gains slightly grow, and infiltration rates marginally decline.

## 5. Conclusion

In this work, a building energy model according to the Passivhaus standard was created and simulated in both current and future weather conditions. It is worth noting that, although the building has a long summer closure period (from July to September), cooling loads still increase (+62,3% in 2020, +128% in 2050, +247% in 2080), due to the high internal loads and high levels of insulation. Indeed, considering global warming, the internal loads worsen the energy behaviour not only in summer but also during the intermediate seasons, accounting for cooling set point temperatures. Therefore, current high-insulated standards should be modified in the future, considering the foreseen temperature trends. In addition, climate adaptation strategies specific for school buildings need further studies to ensure adequate comfort levels in classrooms and to avoid the risk of overheating.

Finally, the sensitivity analysis shows that considering an improved solution different from the one required by the current legislation could be less effective in terms of energy saving under future weather scenarios. This is worth considering, because high-insulated solutions are not very cost-effective and can have high environmental impacts, contributing to the emissions of greenhouse gases. Therefore, choosing the most effective design solutions in a changing climate is challenging. A legislation that takes into account the new needs related to climate change is required to help designers, in order to create resilient buildings.

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