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ANALYSIS OF CLIMATE CHANGE IMPACT ON THE ENERGY PERFORMANCE OF SMALL DWELLINGS LOCATED IN PORTO

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Abstract The energy performance of buildings is heavily affected by weather conditions. This study evaluates the impact of climate change on the heating and cooling energy demand in dwellings located in Porto, Portugal. A synthetic dataset of 50 generated two-storey residential buildings is evaluated using dynamic simulation to assess the energy consumption for air-conditioning in three future climate change weather years. The reference weather dataset corresponds to representative months of measurements from the 1990s, while the future weather data (30-year means) are morphed from Global Circulation Model (GCM) Hadley Centre Coupled Model, version 3 (HadCM3), for the projected years of 2020, 2050, and 2080. The main conclusions are that energy demand will increase in every climate change projection year for all generated buildings and some geometries present higher resilience to energy performance variation, thus requiring further studies to determine the best design guidelines for future scenario of warming climate.

1. INTRODUCTION

Climate change might have multiple impacts on the built environment, most prominently on building energy demand and human comfort [1–5]. For example, in warmer regions, like Southern Europe, where most dwellings still rely on natural ventilation for cooling, the impact on thermal comfort can be significant in terms of health, well-being and energy consumption. This is particularly important for the existing building stock, which was not designed considering the projected future climate conditions and is prone to be subjected to interventions with the purpose of improving thermal performance [6]. Building design must thus respond not only to actual but also future conditions. Current and future climate severity of the seasons will have a direct repercussion in energy consumption to provide an adequate indoor environment to residential buildings [7].
There are already several methodologies to generate future weather data for building simulation [8]. The resulting future typical meteorological year datasets can then be used in the design and modifications of buildings to maintain human thermal comfort [3]. Several studies show that future energy demand by current buildings tend to decline for heating and increase for cooling [3,5,9–11]. Such demand variations may significantly impact the operational parameters of energy production, as well as their feasibility [5,10]. Also, bioclimatic strategies in particular locations must be re-evaluated in order to design new and retrofit existing energy efficient contemporary buildings with comfortable indoor thermal conditions [11].
This work evaluates the effects of climate change on the heating and cooling energy demand in 50 single-family residential buildings located in Porto, Portugal, for the meteorological years of 2020, 2050 and 2080, in comparison with a reference weather dataset of measurements in the 1990s.

2. METHODOLOGY

Fifty residential buildings were generated using the EPSAP algorithm [12–14], which consists of a hybrid evolution strategy that generates alternative building designs by finding the indoor space arrangements by adjusting the rooms and openings geometry to fit a set of design objectives, such as connectivity, non-overlap, non-overflow, dimensioning, compactness, accessibility, construction areas, etc. The generation requirements used in this work correspond to a two-storey family dwelling comprising a hall, a living room, three bedrooms, a kitchen, two bathrooms, a corridor, and a staircase. The buildings' construction elements and their main properties – which are considered to remain constant throughout the 1990-2080 timespan – are presented in Table 1. Afterwards, the energy performance was assessed by dynamic simulation in EnergyPlus (version 9.0.1) [15,16]. The buildings are occupied by five people, with the occupation, lighting and equipment profiles corresponding to a typical working-class family, and are located in Porto, Portugal. Heating and cooling are considered in the living room and bedrooms during the occupation periods, using the ideal loads air system model of EnergyPlus, which simulates an ideal air-conditioned system, thus being possible to directly evaluate the spaces' heating and cooling requirements (*i.e.*, energy consumption equals energy demand). The indoor temperature thermostat setpoints for cooling and heating are 25.0 °C and 20.0 °C, respectively. Exhaust ventilation is considered in the kitchen and bathrooms – 0.6 ACH during occupation –, while 0.2 ACH and 0.1 ACH are considered for outdoor air infiltration into zones with and without exterior openings, respectively.

Table 1: Buildings' construction elements.

Element	Thickness (m)	U ($W.m^{-2}.K^{-1}$)	SHGC
Roof	0.35	0.36	-
Ground floor	0.33	0.44	-
Exterior Wall	0.38	0.43	-
Suspended Slab	0.44	0.42	-
Interior wall	0.11	4.50	-
Interior slab	0.25	2.84	-
Exterior Door	0.04	5.00	-
Interior door	0.04	2.01	-
Exterior window	-	2.40	0.6

In this work, existing typical weather conditions data for the location of Porto, Portugal, is morphed to predict three long-term climate changes, in order to enable energy and building performance simulations. The generated weather data result from using the CCWorldWeatherGen software [17] presented in ref. [18] (other weather generators are discussed in ref. [8]). The Global Circulation Model (GCM) Hadley Centre Coupled Model, version 3 (HadCM3) [19] is used to generate the future weather. In the scope of this work, the reference weather dataset corresponds to representative months of measurements in the decade of 1990, while the future weather data (30-year means) are morphed for 2020, 2050, and 2080 years. Some limitations were found relatively to the use of synthetic weather files, being the main one the absence of extreme weather events (the same can be said about current weather files), such as heat waves and storms, which are becoming more and more frequent, and are very dependent of uncertainties [8].

The synthetic buildings dataset is publicly available in an open access repository (see ref. [20]), with the buildings' construction, geometry, and performance data in the referred climate change years.

3. RESULTS AND DISCUSSION

Figure 1 depicts the energy performance results for total energy, heating energy, and cooling energy consumption for the fifty generated buildings according to the reference weather data (decade of 1990) and weather-morphed HADCM3 projection years (2020, 2050, and 2080). It is possible to observe the increase of energy consumption in the future years. It is also observable that relatively to the reference weather data, where the heating energy demand is higher than the cooling energy demand, the following projections show an inversion between heating and cooling demand and the continuous trend of higher cooling energy consumptions.

In comparison to the reference weather data, the total energy consumption increases 12 %, 37 %, and 73 % for the HADCM3 projection years 2020, 2050, and 2080, respectively.

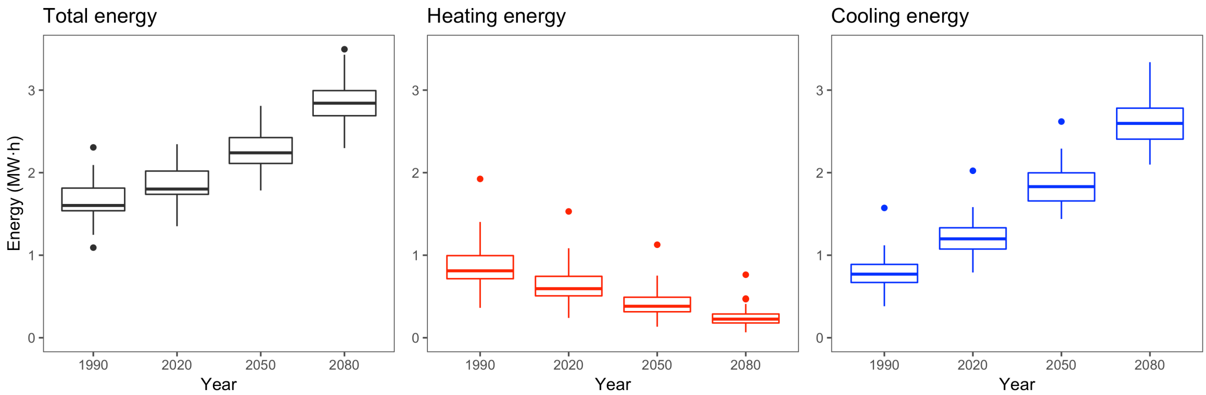

Figure 1: Total energy, heating energy, and cooling energy consumption boxplots for reference weather data (decade of 1990) and weather-morphed years data (2020, 2050, and 2080) in Porto, Portugal.

Figure 2 depicts all generated buildings energy performance. The five buildings presenting the lowest and highest total energy performance variation are marked with dots and colour in the top and bottom graphs, respectively. The results show that the buildings presenting the lowest total energy variation (most resilient) rank within the worst performance in the reference weather data (decade of 1990). However, as time progresses, the total energy performance of the remaining buildings worsens and those buildings improve their ranking. This happens because those buildings currently present low cooling demand, which is beneficial in future years of warming climates (2020, 2050 and 2080), as the heating demand continuously decreases. In other words, the buildings that today are characterized as having cold indoor environments show to be more resilient against the future warmer scenario.
The buildings' total energy consumption variation ranges between 1 % and 25 %, between the years 1990 and 2020, 14 % and 67 %, between 1990 and 2050, and 37 % and 127 %, between 1990 and 2080.

4. CONCLUSION

The generated buildings show that, for each future climate change projection year, the energy performance is greatly affected, which may reach up to a 127 % increase for individual buildings and 73 % on average. When comparing with 2020, the building performance shifts from buildings largely demanding heating to requiring cooling climatization. Also, the dataset presents some cases where some buildings have lower energy performance variation, thus demonstrating that some geometries have higher robustness performance and others not. Further studies on these outlying buildings may allow to determine future design guidelines to assist building practitioners. These preliminary results also rise questions on the adequacy of the current building energy codes, for example if it will contribute to the increase of the cooling energy demand in the future.

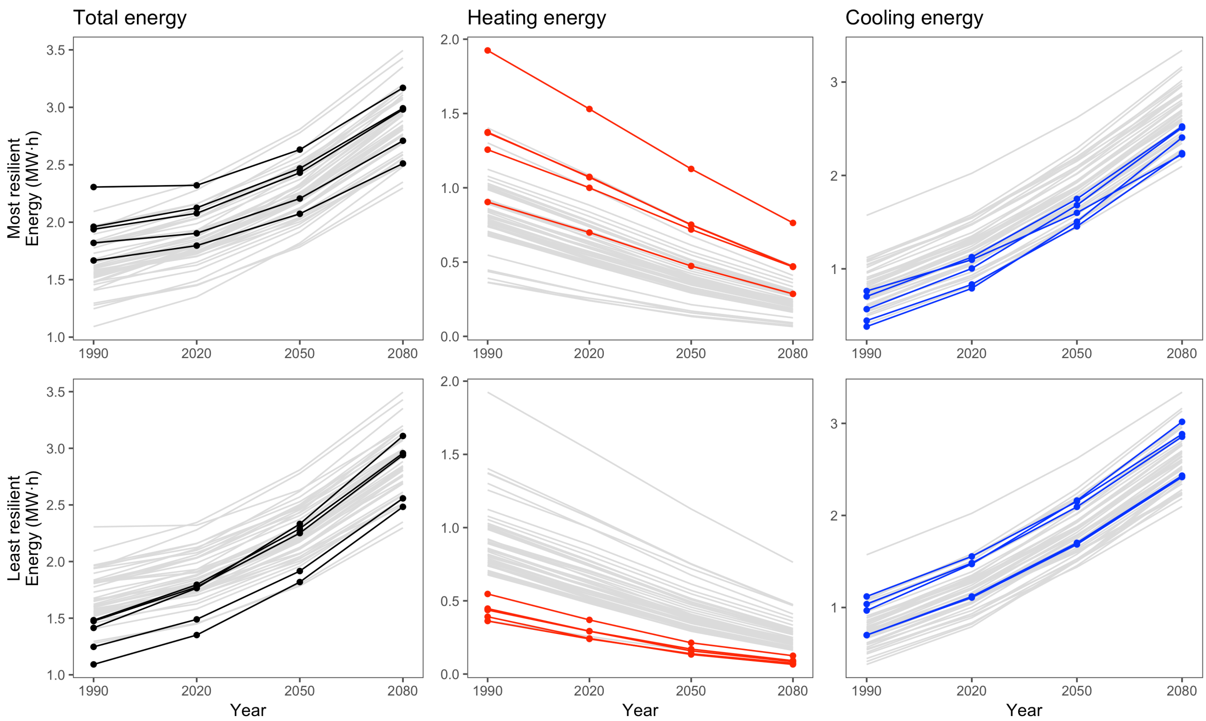

Figure 2: Total energy, heating energy, and cooling energy consumption per building for reference weather data (decade of 1990) and weather-morphed years data (2020, 2050, and 2080) in Porto, Portugal. The five least and most resilient buildings are marked with dots and colour (total energy performance variation).

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