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Energy retrofit for a climate resilient child care centre

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ABSTRACT

Climate scientists have developed and refined climate change models on a global scale. One of the aims of these models is to predict the effects of human activities on climate, and thus the delivery of information that is useful to devise mitigation actions. Moreover, if they can be properly downscaled to a regional and local level, they might be useful to deliver support for adaptation actions. For example, they may be used as an input for the better design of the features of buildings in order to make them resilient to climate modification, e.g., able to passively control heat flows to produce comfortable indoor conditions not only in the present climate, but also in future climate conditions. Taking into account the future weather scenarios that show an increase in the global temperature and climate severity, a likely consequence on building energy use will be a substantial shift from space heating to space cooling, and potentially uncomfortable thermal conditions during the summer will became a major challenge, both for new and existing buildings. In this paper, a deep energy retrofit of a child care centre located in Milan (Italy) is analysed on the basis of future weather scenarios; the analysis aims to identify to what extent choices that are made nowadays on the basis of a typical meteorological year may succeed to provide acceptable energy and indoor environmental performance throughout the future decades. The analysis confirms that climate change might require the installation of active cooling systems to compensate for harsher summer conditions over a long-term horizon, however, in the mid-term, passive cooling strategies combined with envelope refurbishment may still guarantee thermally comfortable conditions, and they will reduce energy cooling needs when active cooling is eventually installed.

1. Introduction

The average temperature of our planet is increasing rapidly. According to the analysis performed by NASA in 2015, the year 2014 was the warmest on record (since 1880), and this trend is expected to continue over the long term [1]. At the beginning of 2016, NOAA and NASA reported that 2015 was by far the hottest year on record globally. NOAA [2] also reported that “During December [2015], the average temperature across global land and ocean surfaces was 2.00 °F (1.11 °C) above the 20th century average. This was the highest for December in the 1880–2015 record, surpassing the previous record of 2014 by 0.52 °F (0.29 °C). The December temperature departure from average was also the highest departure among all months in the historical record and the first time a monthly departure has reached +2 °F from the 20th century average”. The working groups of the Intergovernmental Panel on Climate Change (IPCC) have developed scenarios for both contaminant emissions and global warming [3,4]; these scenarios are able to describe the likely average global conditions in the future. However, local climate scenarios are required in order to design our built environment to be able to withstand future weather conditions. ASHRAE fundamentals 2009 states in Chapter 14: “The evidence is unequivocal that the climate system is warming globally (IPCC 2007). The most frequently observed effects relate to increases in average, and to some degree, extreme temperatures” [5]; and it reports the results obtained by Thevenard [6] according to which design condi-

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Abbreviations: ASHRAE, American Society of Heating Refrigerating and Air Conditioning Engineers; CSI, Climatic Severity Index; CO_2, carbon dioxide; CDD, cooling degree-days; HDD, heating degree-days; GCM, general circulation model; GCSI, Global Climate Severity Index; HadCM3, UK Met Office Hadley Centre Coupled Model version 3; HVAC, heating ventilation and air conditioning; IAQ, indoor air quality; IPCC, Intergovernmental Panel on Climate Change; NASA, National Aeronautics and Space Administration; NOAA, National Oceanic and Atmospheric Administration (USA); TMY, typical meteorological year; TRY, typical reference year; IGDG, Italian climatic data collection "Gianni De Giorgio".

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tions, heating degree days and cooling degree days were all found to have significantly modified values.

By adopting the *morphing* methodology presented by Belcher et al. [7], three different future weather scenarios were developed for the city of Milano, and the deep energy retrofit design of a child care centre [8,9] was assessed against them, in order to evaluate the building resilience to future local climate change.

2. Background

The Italian educational buildings stock consists of 52 000 buildings, of which about 63% were constructed before 1973 [10], the year of the first oil crisis, which provided the initial *stimulus* towards the introduction of energy efficiency targets in building regulations. The energy retrofit of such a large and old building stock, which is mostly owned by local governments, can yield significant improvements in energy efficiency (EE). Constructions from before the first Italian law on energy performance in buildings (Law n. 373/1976), especially in the 50′s and 60′s, are characterised typically by a very poor performance. Hence, the case study presented in this paper, the retrofit of a building that was constructed in the 80′s, might provide a conservative estimation of the energy savings that could potentially be obtained if a similar retrofit strategy were applied to buildings constructed between the 50′s and 70′s. However, also the envelope of the pre-retrofit child care centre, analysed here, presents a poor thermal performance, as indicated in Table 1.

Educational buildings capable of high energy performance have been built in the last decades, sometimes showing problematic issues on the side of thermal comfort (TC) and indoor air quality (IAQ) [11]. For example, higher ventilation rates in order to improve IAQ imply more energy use, and care in design and control is needed to find a sensible balance. A potential ‘EE-TC-IAQ dilemma’ in high-performance educational buildings in the Netherlands has been analysed through measurements and surveys and it is presented in [12].

Another challenge is that even high-performance buildings and zero-energy buildings are designed using current or historical data such as typical weather data files e.g. Typical Reference Year (TRY), Typical Meteorological Year (TMY) and, in the case of Italy, weather files of the Italian Climatic data collection “Gianni De Giorgio” (IGDG), all of which are based on weather data parameters measured in a time span of the order of twenty years in the past [13]. This results in a lack of analysis of the behaviour of those buildings during their lifetime where climate patterns might be significantly different from present and past patterns. In order to contribute in filling this gap, this paper focuses on the resilience assessment of a high-performance retrofit for a child care centre against future weather scenarios. To achieve this aim, in parallel to an analysis of energy performances, the long-term thermal discomfort indices proposed in the European standard EN 15251 [14] are used to assess the indoor thermal comfort conditions, and suitable climate severity indices have been applied to characterise the severity of a few future weather scenarios.

2.1. *Climate severity*

Phillips and Crowe [15] define climate severity as “an unfavourable aspect of climate that arises as a consequence of certain adverse climate elements, occurring either singularly or in combination, and persisting beyond some minimum duration and/or at an intensity above some critical threshold”. It was also pointed out that “duration, frequency, extremes and variability are important statistics that should be considered part of any scheme that attempts to quantify the unfavourable aspects of climate” [15]. One of the first examples is the *Climatic Severity Index* (CSI) that was proposed by Markus et al. [16], which defines, by a single number on a dimensionless scale, “the stress placed on a building’s energy system by any given climatic *stimulus*”.

For the specific case of buildings, the climate severity can be expressed in various ways. A particularly simple way is by using the *Heating degree-days* (HDD) *index*, i.e. the cumulative number, computed over a year under ‘representative’ weather, of the products of a time interval (a day) and the sole positive difference between an outdoor reference temperature (below which a building needs to be heated[1]) and the outdoor air temperature. In case a conventional value for the *building balance-point temperature* is assumed, e.g., 18 °C in Europe and 65°F in the USA, the number of HDDs becomes independent of the features of the building and can be used as a concise description of the cold season climate; it is often used for climatic classification purposes in legislation [17]. The great diffusion of mechanical cooling systems fostered the definition of a similar index for the warm season, i.e. the *Cooling degree-days* (CDD). However, not all of the national legislations have included a classification of climatic zones for cooling needs [18]. The heating and cooling degree-days, based on a conventional choice of the building balance-point temperature, have the advantage of being independent from the specific building features and being easily available, see e.g., [19]. Caution should be used anyway, and one should check how the tabulated values are calculated for both the reference temperature and the time step for calculations (hourly, daily) [20], since these may differ from country to country. Moreover, degree-days cannot capture the dynamic effects due to solar irradiance (excluding the indirect effect on external temperature), which depend on many factors including the building’s orientation, the window-to-wall ratio, the optical properties of the glazing systems (including fixed/movable solar shading devices), the thermal mass of the building etc. Thus, degree-day analysis can lead to large deviations when compared to energy simulations [21]. More detailed methods have been developed in order to include the building thermal dynamics during the whole year in a single value metric. For example, Burmeister and Keller [22] and Keller and Magyari [23] propose an ordinary differential equation for an energy balance of the indoor air temperature, which includes information on the thermal mass, the thermal transmittance of the external walls, the air change rate and the total solar energy transmittance of transparent elements, condensed into three parameters named the *generalised loss-factor*, the *time constant* and the *gain-to-loss ratio*. The equation also includes a building-specific meteorological function, which depends on the external air temperature, the solar irradiance on the façade and the gain-to-loss ratio. The model allows for the calculation of the free-running temperature of a room, and it helps when making decisions at an early-design stage, when it is still not possible or desirable to handle a large number of parameters. The objective is to “arrive at the lowest possible energy consumption of a room, construct it in a way, that its free-run-temperature[2] remains the most part of the year within the comfort range [. . .]. This strategy minimises not only the energy need but also the peak powers needed for heating and/or cooling” [23].

In recent years, an Italian research group led by Terrinoni developed a new index that tackles the climate severity of the summer season [18,24,25]. The proposed *Summer CSI* is determined from hourly calculations and takes into account the outdoor air

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[1] This temperature is called the *building balance-point temperature* and it is defined as the value of the outdoor air temperature at which, for a specified value of indoor temperature (set-point), the total heat loss is equal to the free heat gain (from occupants, lights, sun etc.). The building balance-point temperature is a consequence of the functions and features of the building rather than just the outdoor weather conditions.

[2] Note of the authors: usually the *free-run-temperature* mentioned here is generally called *free-running temperature* in the literature.