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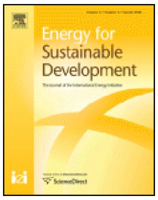

Climate change and the building sector: Modelling and energy implications to an office building in southern Europe

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ABSTRACT

The building sector is one of the most relevant sectors in terms of generation of wealth and occupation, but it is also one of the main contributor to energy use and greenhouse gas emissions (e.g. at the European level it is currently responsible for 36% of CO_2 emissions). For these reason this sector must play a key role in achieving a low-carbon economy consistent with the objective of holding the increase of the average temperature of the globe below 2 °C if compared to pre-industrial levels.

In this context, the paper analyses the potential impact of climate change on the energy uses for heating and cooling in southern Europe, based on the assumptions of the latest Intergovernmental Panel on Climate Change (IPCC) future climate projections (assessment report 5). Different General Circulation Models (GCMs) were analysed using different metrics for selecting the most suitable one to be applied to building simulation. GCM data were used as input to a downscaling method known as “morphing”, to generate hourly weather files for 3 future time projections (2035, 2065 and 2090). Finally, in order to assess the building energy use for heating and cooling for the next century, energy simulations for a case study were performed.

The results show, in all scenarios, consistent and large increases in future air temperature. The impacts of these driving forces on heating and cooling energy use are very relevant: the results show an overall increase in total energy consumption with a relative decrease in heating demand and increase in cooling demand: the yearly heating and cooling energy requirement in 2090 is expected to increase in a range of +50.8–119.7% if measures are not foreseen to counter and limit the effects of climate change.

Introduction

Motivation

Over the last decades, the international scientific community has focused significant efforts to quantify the potential impacts of greenhouse gas emissions due to anthropogenic causes on the climate. In particular, the last assessment report on climate change (IPCC's Fifth Assessment Report (AR5)) presented by the Intergovernmental Panel on Climate Change (IPCC) reveals a historical peak in atmospheric concentrations of carbon dioxide, methane and nitrous oxide (Pachauri et al., 2014). For example, in the period between 2002 and 2011, CO_2 emissions from human activities rose by 54% compared to 1990 (Mazo, Delgado, Marin, and Zalba, 2012) (Stocker et al., 2013). These rates of increase in emissions have contributed significantly to global warming (0.85 °C between 1880 and 2012; 0.72 °C for the 1951–2012 period) (Stocker et al., 2013) and can contribute to a wide range of phenomena such as increased levels of ultraviolet radiation from reduced cloud cover, sea levels rise, increased intensity of storm events and changes in rainfall patterns.

In this context, the building sector is a significant contributor to greenhouse gas emissions (Cellura, Di Gangi, Longo, and Orioli, 2013a; Cellura, Guarino, Longo, Mistretta, and Orioli, 2013b). For example, at the European level about 36% of CO_2 emissions are related to buildings. For this reason, the European Union (EU) has identified the building sector as one key area for achieving its objectives for greenhouse gas emission reductions. This is addressed in the EU directive on the energy performance of buildings (EPBD Recast (Recast, 2010)) which is the basis for national regulations to be implemented in member states. In particular this directive specified that by the end of 2020, all new buildings shall be nearly Zero Energy Building (nZEB) defined as very high-energy performance buildings, the energy needs of which are covered at a significant extent by energy from renewable sources, such as solar (photovoltaic and thermal systems), wind, geothermal and biomass (Beccali, Cellura, Fontana, Longo, and Mistretta, 2013; Beccali, Cellura, and Mistretta, 2007; Cellura, La Rocca, Longo, and Mistretta, 2014; Cellura, Guarino, Longo, and Mistretta, 2015).

Since the long lifetime of buildings (in the range of 50–100 years) corresponds to the timescale over which the climate is expected to

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Nomenclature

IPCC	intergovernmental panel on climate change
AR5	IPCC's Fifth Assessment Report
nZEB	nearly Zero Energy Building
EU	European Union
SRES	Special Report on Emissions Scenarios
TAR	IPCC's Third Assessment Report
AR4	IPCC's Fourth Assessment Report
RCP	Representative Concentration Pathways
GCM	General Circulation Model
CMIP5	Fifth Coupled Model Intercomparison Project
Rh	relative humidity
ghr	global horizontal radiation
dbt	dry bulb temperature
MBE	mean bias error
RMSE	root mean square error
CV(RMSE)	coefficient of variation of the root mean square error
T_{GCM}	General Circulation Model monthly mean air temperature
$T_{ERA\text{-}Interim}$	ERA-Interim monthly mean air temperature
$\overline{T}_{ERA-Interim}$	mean of the ERA-Interim monthly mean air temperatures
i	month
IWEC	International Weather for Energy Calculation
p	predicted value of the atmospheric pressure
p_0	present value of the atmospheric pressure
r	predicted value of global horizontal radiation
r_0	present value of global horizontal radiation
t	predicted value of dry-bulb temperature
t_0	present value of dry-bulb temperature
$\overline{t}_{0\ max}$	monthly mean of the current daily maximum temperature
$\overline{t}_{0\ min}$	monthly mean of the current minimum daily temperature
x_0	current hourly climate variable
WWR	window-to-wall ratio
αr_m	scaling factor in monthly global horizontal radiation for the month m
αt_m	scaling factor for the dry-bulb temperature
Δp_m	monthly increment in atmospheric pressure
Δr_m	absolute increment for monthly average solar short-wave flux received at the surface
Δt_m	predicted monthly daily mean temperature
$\Delta t_{max\ m}$	predicted monthly daily maximum temperature
$\Delta t_{min\ m}$	predicted monthly daily minimum temperature

show substantial change, the buildings constructed today need to be resilient to future climates (Guan, 2012; Hamdy, Carlucci, Hoes, and Hensen, 2017; Pyke, McMahon, Larsen, Rajkovich, and Rohloff, 2012; de Wilde and Coley, 2012), potentially largely different than the one we are experience today.

Therefore, predicting future climatic conditions is the starting point to all building climate change impact studies. These scenarios are description of alternative futures, where total greenhouse gas emissions and the resulting global temperature increase are projected on the basis of various socio-economic factors affecting emission levels, including population growth, economic activity, technological change, as well as governance and cultural values. These scenarios typically compare the anticipated effects of various parameters with a 'business as usual' situation, and play an important part in both policy development and climate change negotiations on a national and global level (Ng, Baum, Dafoe, and Gaffney, 2017).

Future climate change scenarios

Over the last two decades IPCC has released several classes of emissions scenarios that differ between them for several factors such as population expected growth, economic development or development of new technologies.

In 1990 IPCC published the first set of emission scenarios, called SA90 (Houghton, Jenkins, and Ephraums, 1990). In 1995, a second group of emission scenarios, called IS92, was released (Change, 1996). In 2000, a third generation of projections was released, collectively referred to as the Special Report on Emissions Scenarios (SRES). These were used in two subsequent reports; the Third Assessment Report (TAR) (Change, 2001) and Assessment Report Four (AR4) (Team et al., 2007) and have provided common reference points for climate science research in the last decade. Finally, in 2007, the IPCC responded to calls for improvements to the SRES scenarios by developing four emissions scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5), defined as Representative Concentration Pathways (RCP) that were used in the last IPCC assessment report (AR5) (Pachauri et al., 2014). Compared to their predecessors, the RCP scenarios consider new and larger amounts of data such as socio-economic aspects, emerging technologies and land cover changes. Another key difference is that the RCPs are also more detailed in the geographical spacing, providing information with a global grid with a resolution of approximately 60 km (it was 110 km in the Fourth Assessment Report).

Each RCP scenario represents a rough estimate of the radiative forcing (defined as the additional power taken up by the Earth as a system due to the enhanced greenhouse effect) expected to take place under certain assumptions. More precisely, it can be defined as the change in the net radiative flux through atmosphere due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide (Stocker et al., 2013).

As shown in Table 1, the four RCP scenarios include a mitigation scenario, two intermediate scenarios and one scenario with very high Greenhouse Gas emissions. In detail, RCP2.6 is a scenario that aims to keep global warming below 2 °C above pre-industrial temperatures and to pursue efforts to limit this increase to 1.5 °C through a nearly full decarbonisation of the economy, while RCP8.5 is a business as usual scenario, with no policy changes to reduce emissions (three times today's CO_2 emissions by 2100) (Moss et al., 2010).

Global circulation models and applications to building simulation

The emission scenarios do not strictly include climate change predictions, but they rather represent possible development pathways of human activities, they model the cause to climate change, through realistic pathways and assumptions, to be used as a baseline for the climate change modelling. Therefore, emission scenarios are used as input to General Circulation Models (GCMs) to obtain predictions of the future climate. GCMs are essentially mathematical models of the general circulation of a planetary atmosphere, which describe the most important components, processes and interactions in the climate system. The GCMs predict climate at a relatively high level of spatial and temporal resolution. Driven by the fact that assessing the impact of climate change on building performance requires local weather data at higher temporal resolution, the global circulation model outputs have to be “downscaled”, referring to a process of generating climate change information at spatial and temporal scales lower than those provided by the GCMs.

To adapt GCMs outputs and assess the impact of climate change on building performance two different approaches can be usually found in the state of the art (Cox, Drews, Rode, and Nielsen, 2015): statistical methods and building simulation approaches.

Statistical analyses are usually used to model the relationship between the local meteorological parameters (degree-day, dry-bulb temperature or wet-bulb temperature) and the specific building energy demand based on the sufficient historical observed data. These relationships can be used as means to predict future weather conditions, however without the consideration of the relationship between the building envelope and the outdoor environment.