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Utilization of Climate Files Predicting Future Weather in Dynamic Building Performance Simulation – A review

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Abstract. As the climate is changing and buildings are designed with a life expectancy of 50+ years, it is sensible to take climate change into account during the design phase. Data representing future weather are needed so that building performance simulations can predict the impact of climate change. Currently, this usually requires one year of weather data with a temporal resolution of one hour, which represents local climate conditions. However, both the temporal and spatial resolution of global climate models is generally too coarse. Two general approaches to increase the resolution of climate models - statistical and dynamical downscaling have been developed. They exist in many variants and modifications. The present paper aims to provide a comprehensive overview of future weather application as well as critical insights in the model and method selection. The results indicate a general trend to select the simplest methods, which often involves a compromise on selecting climate models.

1. Introduction and background

Climate change is one of the greatest challenges of modern-day society. Based on observed data, the total increase in average temperature between periods 1850-1900 and 2003-2012 is 0.78 °C [1]. The building sector is one of the main greenhouse gas emitters, responsible for around 19% of the worldwide greenhouse gas emissions [1]. These trends call for evermore sustainable and energy efficient buildings. During a lifetime of more than 50 years, current buildings will be exposed to progressively warmer weather, increased frequency of heavy precipitation events, and other climate change phenomena [1], which can have a negative impact on their performance. Therefore, it is reasonable to account for future climate during building design.

Building performance simulation (BPS) is an essential tool for predicting the building energy demand and indoor environmental quality. Various formats of weather data are used in building simulation, but they generally include air temperature, air humidity, solar radiation, as well as wind speed and direction at an hourly temporal resolution as a minimum. Traditionally, a meteorologist applies a set of ranking criteria to the individual months of a continuous 20-to-30-year historical observed data set and assembles a year of 12 typical months to create a weather file [2]. The number of years required to create a weather file is arbitrary, but mostly a period of 30 years is used, as it is equivalent to the climate standard normal period [3].

Climate scientists worldwide use Global Climate Models (GCM) and Regional Climate Models (RCM) to predict the future climate. These are simulation models representing physical processes in the atmosphere, ocean, cryosphere, and on land. RCMs typically simulate a region over a large land area at higher spatial and temporal resolution compared to the global scale of GCMs. A RCM is



typically nested within a GCM, which provide an initial condition and time dependent boundary conditions for the RCM [4]. Each RCM can be used to downscale multiple GCMs.

For each Coupled Model Intercomparison Project (CMIP), climate models use a standardized set of forcing scenarios released by the International Panel on Climate Change (IPCC) to simulate climate systems response to increasing greenhouse gas concentrations. CMIP3 (~2005 to 2010) uses Special Report on Emissions Scenarios (SRES) [5], CMIP5 (2010 to 2014) uses Representative Concentration Pathway (RCP) [1], and CMIP6 (2013 to ~2022) uses Shared Socioeconomic Pathway (SSP) [6]. The current spatial and temporal resolution of GCMs is too coarse for BPS. Therefore, studies on the subject use various methods to increase the spatial and temporal resolution to create suitable future weather files. These methods are commonly referred to as downscaling and there are two main approaches, dynamical downscaling, and statistical downscaling [7]. A third less commonly used approach, hybrid downscaling is a combination of the two main approaches [8].

The purpose of this study was to review studies using future weather data in building performance simulations. We present a large collection of studies, summarizing key attributes of each study to get an overview of the topic.

2. Methodology

The literature search comprised the search engines DTU Findit, Web of Science, Elsevier search results, Mendeley, Google scholar, and DuckDuckGo. The most frequently used keywords were: *climate, change, future, weather, data, building, performance, simulation, impact, study, heating, cooling, ventilation, and overheating*. The criteria for considering a study in the results of the present paper were that it must present results from a BPS using predicted future weather data. Additionally, only fully dynamic BPS tools were considered, tools using quasi steady-state calculation approach were excluded.

3. Results

We reviewed a total of 109 full articles of which 47 were identified as climate change related building performance simulation studies. The 37 studies are listed in Table 2 and have covered 164 locations. As the simulation studies dealing with predictions of building performance in the future are receiving increasing attention, a webpage was created, that allows an easy update of the current list of identified studies (www.futureweatherbps.com). The downscaling method column (Table 2) discloses how the climate data was downscaled and or converted into a weather file usable for BPS. Morphing was the most used downscaling method (33%) followed by CCWorldWeatherGen (CCWWG) (24%) or directly simulating an output from dynamically downscaled data from RCM(s) (24%). The 47 studies use a selection of 61 different GCMs. Each GCM is used by one to eight studies, except for HadCM3, which is used by 21 studies indicating that HadCM3 might be overrepresented in the literature. More than a half of the studies from 2015 or newer rely solely on outdated data from CMIP3. This is partially attributed to the continued use of the weather generator tool CCWorldWeatherGen. One reason why the CCWorldWeatherGen tool is still being used is that it is easy to use as it generates EnergyPlus or TMY2 weather files directly. Although many studies are aware of the uncertainties involved in climate modelling, only five studies have described their method for selecting climate models and they generally follow the IPCC criteria. Omitting climate model selection is problematic as climate models differ widely [9] and using a climate model in the extreme end of the entire ensemble can lead to misleading results.

Some examples of methods include Liu et al. [10] creating a TMY weather file from historical data and using it together with averaged data from 24 GCMs to make six future weather files (three time periods and two RCP scenarios). Bravo Dias et al. [11] compare three downscaling methods: morphing, dynamical downscaling, and CCWorldWeatherGen. Generally, most studies compare the future weather with historic data from the same climate model, but Silvero et al. [12] compares the results of the future weather with results from the observed weather because historic data from 2009 from the MOCH-HadGEM2-ES model was not available.

Four studies [8,11,13,14] have compared weather files obtained by different methods. Judging by the mean temperatures, the downscaling methods for creating future weather file ranked from lowest to highest temperature increase are: dynamical downscaling, morphing, Meteonorm, CCWorld-WeatherGen, and WeatherShift. Fernández et al. [15] compared a large ensemble of climate models and found RCMs to be skewed towards lower temperatures compared to GCMs, which supports dynamical downscaling having smaller temperature increase than GCM based downscaling methods.

Our review suggests (Table 2), there is a general trend to select the simplest methods. Thirty studies use output data from a single climate model. Twelve studies use multiple climate models, but only three of them [8,16,17] implemented at least four variables: dry bulb temperature, relative humidity, solar radiation, and wind speed with wind direction from the baseline weather file. Others excluded wind speed [10,18,19] or used dry bulb temperature only [20–22] which is not meteorologically consistent unless the other variables are adjusted.

Many studies use BPS to compute the increase in cooling demand and decrease in heating demand caused by the climate change. Their results are illustrated in Table 1. The differences in predicted change in cooling demand, and heating demand (with respect to the particular baseline) cannot be directly compared. They vary according to the different climate models and downscaling methods applied as well as the different approaches to simulation of heating and cooling. However, Table 1 indicates that there is a much larger spread in predicted cooling demand than in predicted heating demand. With respect to the cooling demand the predicted increase is in the range from 12 to 375 %.

In addition to the many different methods used by different studies to create future weather files, there are particularly many ways to treat the solar radiation data. The root of the problem is that GCMs and RCMs only provide the global horizontal irradiance, while direct normal irradiance and diffuse horizontal irradiance is required for BPS. Clear sky models is a field of study in itself [23] and so far, no studies have investigated, which clear sky model is best suited for climate model outputs. Two examples of approach to using of solar radiation data are following. Jylhä et al. [17] apportion the global solar radiation between direct and diffuse radiation using an empirical approach and utilise an observed average partition between the radiation components. Cellura et al. [24] used the global solar radiation to calculate the direct and diffuse solar radiation based on the ASHRAE Handbook of Fundamentals from 2013. Other studies such as the study by Pouriya and Umberto [13] keep solar radiation from the baseline weather file.

Table 1. A comparison of the change in cooling- and heating demand relative to their baselines.

Ref.	Scenario	Cooling increase	Heating decrease
[25]	RCP2.6 – RCP 8.5	12 - 35 %	No heating demand
[26]	A1F1, A2	17 - 36 %	15 - 49 %
[27]	RCP 4.5	29 - 31 %	21 - 22 %
[13]	A2, RCP 8.5	14 - 55 %	18 - 27 %
[28]	A2	40 - 163 %	24 - 90 %
[22]	A2, A1B, B2	59 - 156 %	23 - 55 %
[10]	RCP2.6 – RCP 8.5	121 - 278 %	No heating demand
[24]	RCP2.6 – RCP 8.5	81 - 375 %	25 - 82 %

4. Conclusion

We presented an extensive review of literature focused on the use of future weather files in building performance simulations. The large number of available climate models brings a high difficulty in selecting the optimum one, which motivated this study. Various downscaling methods can increase the spatial and temporal resolution to create future weather files suitable for building performance simulation. Most use morphing or Climate Change World Weather file Generator, both classified as statistical downscaling while others use dynamically downscaled data from regional climate models. Most studies omit climate model selection and depending on the climate model the results can be misleading.

Table 2. Overview of 37 climate change building performance simulation studies sorted by publication year newest first. This table is based on a survey of published research, and it has been shortened to publications published in 2014 or newer due to page limits. The uncut table is freely available at www.futureweatherbps.com. Keywords are consolidated such that energy- demand, consumption, efficiency, use, becomes energy etc.

Ref.	Purpose	Year	Typology	Location	Project	GCM (RCM)	Scenario	Downscaling	BPS
[28]	Energy	2050	Residential	Medit.	CMIP3	HadCM3	A2	CCWWG	EnergyPlus
[11]	Energy	2080	Office, townhouse	Iberia	CMIP5	HadCM3 (WRF)	A2	CCWWG, Morphing	EnergyPlus
[10]	Energy	2035, 2065, 2090	Rental apartments	Hong Kong	CMIP5	24 GCMs	RCP2.6, 4.5, 6.0, 8.5	Morphing	EnergyPlus
[7]	Overheating, heating, cooling	2011-2040, 2041-2070, 2071-2100	Residential	Paris	CORDEX, CMIP5	11 GCM-RCM combinations	RCP4.5, 8.5	RCM	EnergyPlus
[27]	Thermal performance	2045	Residential	Australia	CMIP5	-	RCP4.5	Statistical	TRNSYS
[12]	Under- and overheating	1990, 2009, 2030, 2050, 2070	Residential	Paraguay	CORDEX, CMIP5	ECMWF-ERAINT, HadGEM2-ES, (RCA4)	RCP4.5, 8.5	RCM, Statistical	EnergyPlus
[13]	Weather file comparison	1959-2075	16 different	Toronto	CMIP3, CMIP5	HadCM3 (HRM3)	A2, RCP8.5	CCWWG, RCM, WeatherShift	-
[25]	Cooling	2020, 2050, 2080	Office	Taiwan	CMIP5	NorESM1-M	RCP2.6, 4.5, 8.5	Morphing	EnergyPlus
[29]	Energy	2030, 2060, 2090	Large office	USA	CMIP5	14 GCMs	RCP4.5, 8.5	WeatherShift	EnergyPlus
[30]	Energy	2020, 2050, 2080	House	Argentina	CMIP3	HadCM3	A2	CCWWG	EnergyPlus
[8]	Weather file comparison	2010-2039, 2040-2069, 2070-2099	16 different	Geneva	CORDEX, CMIP5, CMIP3	4 GCMs (RCA4)	A2, RCP45, RCP85	CCWWG, WeatherShift, Meteorom, RCM	EnergyPlus
[16]	Energy	2048-2100	House	Valencia	CMIP5	CNRM-CM5, MPI-ESM-LR	RCP8.5	Morphing	TRNSYS
[31]	Energy	2020, 2050, 2080	Commercial	Montreal	CMIP3	HadCM3	A2	CCWWG	EnergyPlus
[24]	Energy	2035, 2065, 2090	Office	Europe	CMIP5	24 GCMs	RCP2.6, 4.5, 6.0, 8.5	Morphing	TRNSYS
[32]	Energy, Passive design	2050	House	Córdoba	CMIP3	HadCM3	A2	CCWWG	EnergyPlus
[33]	Energy, Adaptation	2020, 2050	Social housing	Brazil	CMIP3	HadCM3	A2	CCWWG	EnergyPlus

[34]	Passive design	2036-2065, 2066-2095	House, apartment, residential	Firenze	CORDEX, CMIP5	(COSMO-CLM)	RCP8.5	Morphing	EnergyPlus
[35]	Energy	2020, 2050, 2080	Social housing block	Milano	CMIP3	HadCM3	A2	CCWVG	EnergyPlus
[26]	Energy	2050	Residential, office	USA	CMIP3	HadCM3	A1F1, A2	Morphing	EnergyPlus
[20]	Energy	2021-2100	156 residential	Sweden	CMIP3	CNRM-CM3, ECHAM5, (RCA3)	A1B	RCM	Matlab
[36]	Heating	2020, 2030, 2040, 2050	Apartment	Europe, Canada	CMIP3	HadCM3	low, med, hi	CCWVG	Matlab
[37]	Mitigation, Adaptation	2050, 2080	House	Ecuador	CMIP3	HadCM3	A2	CCWVG	TRNSYS
[38]	Overheating, Cooling	2050	Dwelling	Netherlands	CMIP3	5 GCMs (8 RCMs)	KNMI06 G+, KNMI06 W+	Hybrid	IDA
[39]	Energy	2020, 2050, 2080	Office	Chile	CMIP3	HadCM3	A2	CCWVG	Excel VBA
[40]	Regional future weather	2000-2089	Office, hotel, mall	Shanghai	CMIP5	HadGEM2-CC	RCP4.5	Morphing	EnergyPlus
[41]	Energy	2050, 2090	Apartment blocks	Växjö	CMIP5	HadGEM2	RCP4.5, 8.5	Morphing	VIP-Energy
[42]	Energy, Passive design	2020, 2050, 2080	Social dwelling	Brazil	CMIP3	HadCM3	A2	CCWVG	EnergyPlus
[43]	Energy, Passive design	2020, 2050, 2080	Apartment	Taipei	CMIP3	MIROC3.2-M	A2, A1B, B1	Morphing	EnergyPlus
[44]	Heating	2005, 2029	House	Tokyo	CMIP5	MIROC4h (WRF)	RCP4.5	RCM	TRNSYS
[21]	Heating	1961-2100	Building stock	Sweden	CMIP3	5 GCMs (RCA3)	A1B3	RCM	Matlab
[45]	Performance, Aging factors	2010, 2020, 2030, 2040, 2050, 2060	Library	Turin	CMIP3	-	A2, B1	Morphing	IDA
[46]	Energy	1990, 2040, 2090	Office	Japan	CMIP3	MRI-CGCM2 (RCM20)	A2	RCM	TAS
[47]	Passive design	2070	Residential	Adelaide	CMIP3	CSIRO-Mk3.0	A1B, B1	Morphing	AccuRate
[17]	Energy	1980-2100	Not specified	Finland	CMIP3	19 GCMs	A2, A1B, B1	Morphing	IDA
[48]	Energy	2007, 2034	House	Japan	CMIP5	MIROC4h (WRF)	RCP4.5	RCM	TRNSYS
[49]	Energy	2052-2089	Commercial, residential	USA	CMIP3	CASCaDe	A2	Statistical	EnergyPlus
[50]	Heating, cooling	1950-2100	Offices	Wien	CMIP3	(REMO-UBA)	A1B	RCM	TAS

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