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An alternative method to predict future weather data for building energy demand simulation under global climate change

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ABSTRACT

Climate change would affect the building energy demand in the future. Building simulation is a feasible way to quantitatively evaluate this impact. Since the detailed weather is dispensable for the building simulation, it is important to predict the weather data for the future. Given that the uncertainties and limitations of GCMs on regional-scale weather prediction, an alternative method of future weather data generation for future building energy demand simulation is proposed in this paper. Based on the long-/short-term climate periodicity analysis, a Dual-Periodic Time Series Model is established to predict the future monthly temperatures in Shanghai. From the fitting results and the preliminary assessment analysis, it is observed that the alternative forecasting method and the corresponding Dual-Periodic TSM has better capability of characterizing and predicting performance for both recent and future temperature trends in Shanghai than GCM under RCP4.5. In this case, this method can be used as an alternative and supplementary way to the widely used GCM.

With consideration of three composite uncertainty scenarios, we convert the predicted monthly temperatures into hourly TMYs by using Morphing method. Using the future TMYs as the weather input of prototypical building models of Shanghai, we can see that the simulated building energy demand presents fluctuant trends in the future periods, different from the continuous uptrends of that using IPCC RCP4.5.

Abbreviations: GCM, General Circulation Model/Global Climate Model; RCM, Regional Climate Models; IPCC, Intergovernmental Panel on Climate Change; RCP, Representative Concentration Pathways, including four grades: RCP8.5 RCP6 RCP4.5 and RCP3-PD; AR5, IPCC Fifth Assessment Report; TMY, Typical Meteorological Year; HVAC, Heating Ventilation Air-Conditioning; HDD, heating degree days; CDD, cooling degree days; DBT/dbt, dry bulb temperature; WBT/wbt, wet bulb temperature; RH, relative humidity; WS, wind speed; SR, solar radiation; LBNL, Lawrence Berkeley National Laboratory; GHG, greenhouse gas; NCDC, National Climatic Data Center; CMIP5, IPCC's Coupled Model Intercomparison, Phase 5; LIA, Little Ice Age; AMO, Atlantic Multidecadal Oscillation; ENSO, El Nino-Southern Oscillation; TSM, Time Series Model/Method; TC series, the remaining series after excluding a stochastic term (Xt) from the observation series in Time Series Method; Ht/Ht′, trend term in Time Series Model; Pt/Pt′, periodic term in Time Series Model; Xt/Xt′, stochastic term in Time Series Model; Yt/Yt′/Yt″, sum of Ht, Pt, and Xt in Time Series Model; T1/T2, two periods in the proposed alternative forecasting model, respectively identified as the trend and periodic features of the observed temperature series; CSWD, Chinese Standard Weather Data; CTYW, Chinese Typical Year Weather; IWEC, International Weather for Energy Calculation; SWEAR, Solar Wind Energy Resource Assessment; FS, Finkelstein–Schafer method; ΔTMP_m, predicted change of monthly mean dbt of m month in Morphing method; $adbt_m$, monthly stretching factor of dbt in Morphing method; $\Delta TMAX_m$, predicted changes of monthly maximum temperature in Morphing method; $\Delta TMIN_m$, predicted changes of monthly minimum temperature in Morphing method; $(dbt_{0max})_m$, monthly mean daily maximum temperature of m month in existing TMY in Morphing method; $(dbt_{0min})_m$, monthly mean daily minimum temperature of m month in existing TMY in Morphing method; R^2, fitting optimization index; MAPE, Mean Absolute Percent Error; RMSE, Root Mean Square Error; S1m/S2m/S3m, uncertainty scenarios of monthly mean temperature; S1/S2/S3, three composite scenarios, which combine the daily fluctuation scenarios with corresponding fluctuation level of the uncertainty scenarios of monthly mean temperature.

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1. Introduction

The global warming in the 20th century is a significant contribution to the climate change issue, which is a global concern. As one of the top greenhouse gas emitters, China is under multiple pressures of climate diplomacy, economy development needs, resource shortage and environmental deterioration. Therefore, a correct estimate of future energy demand under climate change is significant for relieving the huge international pressure for China. The building industry plays an important role in the energy conservation plan. Nowadays, the building sector consumes one-fifth of energy resources and the corresponding Green House Gas emissions space in China [1]. With the acceleration of urbanization, the proportion of building energy consumption in total energy use will increase. Meanwhile, the climate change has great impacts on the building energy performance. The weather contributes directly and significantly to the thermal loads and the energy use of Heating Ventilation Air-Conditioning (HVAC) systems. In China, The HVAC systems in commercial buildings take more than 50% of the total building energy consumption. As an important part of climate change studies, the prediction of building energy demand under climate change is greatly significant to building energy saving, urban energy planning, urban strategy development and energy policy formulation.

At present, the prediction researches of building energy demand under climate change can be divided into two groups: (1) direct prediction through statistical analysis, and (2) indirect prediction using building simulation tool.

For direct prediction, a statistical analysis method is usually applied to achieve the relationship between the local meteorological parameters (degree day, dry-bulb temperature/wet-bulb temperature) and the specific building energy demand based on the sufficient historical observed data. After a reasonable validation, the relationship can be used as a predictive model. Christenson et al. [2] developed a procedure to estimate the heating degree days (HDD) and the cooling degree days (CDD) from the monthly temperature data of four representative Swiss locations to obtain the past trends of HDD and CDD for the period 1901–2003. The future trends of HDD and CDD in the 21st century, which represent the change of heating and cooling energy demand separately, were assessed based on Intergovernmental Panel on Climate Change (IPCC) emissions scenarios. The degree day method is a simple method, without the consideration on response process of buildings to outdoor environment. There is a basic assumption in many similar researches as the premise of using degree day method. That is: The building energy demand has a significant linear correlation with degree days. In other words, only for the buildings with a relatively constant internal temperature, thermal gains and building properties, this method is reliable for quantifying the building heating/cooling energy demand. By simulating of the different building types with different energy saving levels in Tianjin, China, Li et al. [3] found that CDD is unable to entirely reflect the cooling loads changes of office buildings and retail buildings, since CDD can only explain 64% and 55% of their cooling loads respectively. Comparatively, the relationship between temperatures and building energy consumption used in the direct prediction is more complicated than the simple linear correlation. Lam et al. [4] developed several regression models to correlate monthly building cooling loads and the total energy use of office building in Hong Kong with a new climatic index Z (a function of local dry-bulb temperature, wet-bulb temperature and global solar radiation) in 1979–2008. Future trends of building heating/cooling loads and building energy demand in the 21st century are predicted by the regression models based on IPCC's emissions scenarios in 2001. The average annual cooling load in 2009–2100 would be 9.1% and 10.7% more than that in 1979–2008 respectively under low- and medium-level emissions scenario; the percentage increase for energy use would be 4.3% and 4.9% accordingly.

The rapid development of building simulation technology has provided robust support for building energy demand prediction. The indirect prediction usually needs two main parts as the research foundation:

(1) Generation of hourly future weather data (normally in the form of TMY) under climate change. The existed TMYs are generated from historical weather observations and not respective of future climate conditions.
(2) Establishment of Prototypical Building Models according to related design standards and survey data of local existing buildings. After calibrated by investigated actual energy use data, the models can mainly reflect the general situation of different building types in a specific region. As the indispensable inputs of building simulation, hourly future weather data is a prerequisite and a key point for building energy demand prediction under climate change by taking advantage of building simulation tool.

During 2005–2008, two separate research projects at LBNL [5,6] on the potential impact of climate change on building energy use in California and the US were completed using indirect prediction method. Predicted climate changes for various locations were obtained from General Circulation Models (GCMs). The Outputs of a selected GCM were monthly and daily predicted changes of meteorological parameters (temperature, humidity, and solar radiation) under standard IPCC emissions scenarios. By statistical downscaling method, these changes were then combined with existed TMY files of different locations to get new future TMYs. These new TMYs were then used as weather inputs of prototypical residential and commercial building models to calculate the impacts of predicted climate changes on the heating and cooling energy use. The simulation results showed a 7% decrease in 2020s and a 18% increase in 2080s nationally on a basis of in-site energy use in 1980–2009. By the same method, Chan [7] developed future TMY files for Hong Kong and used them in local prototypical buildings. The simulated results indicate substantial increase in Air-Conditioning energy consumption in 21st century, ranging from 2.6% to 14.3% for office buildings and from 3.7% to 24% for residential flats, respectively.

Currently a majority of similar prediction researches use IPCC's GCM results as their basic data of climate change. However, this important basis of hourly weather data prediction may have great uncertainties. In IPCC's assessment of global climate change, Emission Scenarios (alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions) are supposed to drive GCMs (numerical representation of the climate system based on its physical, chemical and biological properties) for understanding and attribution of past climate variations, as well for future predictions [8]. There are some key uncertainties in the researches: (1) The attribution and the prediction of regional climate change are limited by the complicated climate variability on regional scale. (2) The predictions of climate change are highly scenario- and model-dependent. (3) Considerable differences exist in the results of different models under different feedbacks in the climate system. The focuses of these uncertainties and related exploration from diverse research fields, such as meteorology and geophysics, produces some controversy and query on GCMs' simulation capability for system mechanism of climate change, especially on regional scale [8,9]. Hence there are some certain limitations to apply GCMs' outputs to regional-scale weather data prediction.

Given the uncertainties and limitations of the widely used climate predictions (by GCMs) for generating regional-scale hourly