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Using Typical and Extreme Weather Files for Impact Assessment of Climate Change on Buildings

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Abstract

Considering climate change and assessing its impacts is challenging due to dealing with large data sets and uncertainties. This paper discusses an approach for the impact assessment of climate change based on synthesizing weather data sets out of several climate scenarios, in a way to generalize the assessment despite of the existence of climate uncertainties. The is based on creating one-year weather data, representing typical, extreme-warm and -cold conditions for 30-year periods, which results in decreasing the length of simulations enormously. The usefulness and accuracy of the results are discussed for energy and moisture simulations in buildings.

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Keywords: Climate change; weather data; energy simulation; regional climate models; big data;

1. Introduction

The common approach to assess the impacts of climate change is simulating the studied phenomena using future climate scenarios. Planning for climate change adaptation is complicated since it is difficult to predict the expected degree of warming as well as the expected pace [1]. Impact assessment of climate change is usually performed by means of the climate data generated by global climate models (GCMs) which cannot be considered as weather and are coarse for impact assessment [2]. Regional climate downscaling (RCD) provides projections with much greater detail and more accurate representation of localized extreme events [3]. Dynamic downscaling of GCMs by means of

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regional climate models (RCMs) has the advantage of generating physically consistent data sets across different variables [4] [5]. However, it is not possible to rely on short time spans when dealing with future climate scenarios and periods of 20 to 30 years should be considered. Moreover, there are different uncertainties which affect simulated climate data, such as the selected GCM, RCM, emissions scenario and the spatial resolution [6]. In other words, it is not possible to rely on few climate scenarios and a valid assessment should consider several scenarios (e.g. [7] [8] [9]) and a critical part of the assessment is always the weather data sets which are used in the assessment due to important uncertainties and large data sets (e.g. [6][10]).

Synthesizing weather data sets for energy and building simulations has a long history and several techniques have been developed, which some have been inspiring for creating typical future weather data sets (e.g. [10] [11]). Using typical/representative weather year reduces the computational efforts and data handling loads since it enables using one year for calculations instead of multiple years. Several techniques are available to create typical or reference weather files for energy simulations which Chan et al. have provided a review of some of the most important ones [12]. Creating typical meteorological year (TMY) was introduced by Hall et al. [13], which is based on selecting typical meteorological month (TMM) for each month and concatenating them to create the weather file for one year. Most of the efforts for creating typical future climate files (e.g. [14]) are based on extending the available approaches on statistically downscaled GCM data, which means the climate variations and anomalies inducing more extreme conditions will be neglected.

This article present a simple approach for creating representative future weather data out of RCMs: 1) typical downscaled year (TDY), 2) extreme-cold year (ECY), and 3) extreme-warm year (EWY). The weather data sets can be synthesized out of one or several RCMs, while the latter has the advantage of covering climate uncertainties. The main motivation for creating such weather data sets is decreasing the calculation load while keeping a high accuracy in estimating the variations in hourly time scale. Moreover, it is desired to synthesize weather data sets out of hourly RCM data without weighting the weather parameters in time series (due to inherent uncertainties of future climate). Application of the suggested method is tried for two climate scenarios in Stockholm, investigating the energy performance of the residential building stock in the city.

2. Creating typical and extreme future weather data sets

The representative weather data sets for future conditions, TDY, ECY and EWY, are synthesized for a 30-year period in a similar way as TMY by Hall et al. [13], with the difference of considering only the distribution the outdoor dry-bulb temperature ($T_{dry\text{-}bulb}$) and in the hourly time scale. There are several reasons for not weighting the other climate parameters, such as:

- Climate change does not affect all the climate parameters on the same way and its signals are not visible or do not have the same strength for all the climatic parameters.
- Difficulty in weighting the climatic parameters gets more serious when more than one climate scenario is considered since climate uncertainties affect each parameter separately.
- Since the aim is creating typical and extreme weather data sets, similar indices/parameters should be used in recognizing the typical and extreme data sets.
- Climate data out of GCMs and RCMs reflect the interactions of several components of the climate system, which means each parameter is affected by several other parameters.

The hourly temperature of the 30-year RCM weather data for two scenarios is a 60×8760 matrix, being divided into 12 matrices corresponding to 12 months in a year. For each months, temperature distribution is found by calculating its quantiles for each year separately and for all the 60 years together. The latter is the reference and the year which its quantiles have the least absolute difference from the quantiles of the reference during the considered month, will be selected as the year with the typical meteorological month. This is similar as comparing the cumulative distribution function (CDF) of the single and combined (long-term or reference) data sets to find the one closest to the long-term distribution (which is referred as Finkelstein–Schafer (FS) statistics [13]). For creating ECY and EWY data sets, the procedure is similar, however instead of looking for the least absolute difference, the years with the maximum (for ECY) and minimum (for EWY) difference (the real number) are selected (for more details the reader is referred to [10]).

3. The considered building stock

The numerical model of the building stock in Stockholm, developed in Matlab/Simulink, has been used previously to simulate and assess future conditions for the residential building stock in Stockholm, considering several climate scenarios and uncertainties [15]. The building stock of Stockholm is statistically represented by 153 sample buildings from the BETSI investigation by the Swedish National Board of Housing, Building and Planning (Boverket) in year 2009 [16], which is the major source of information for the energy performance of residential buildings in Sweden and has been used previously in several works (e.g. [15][17][18][19]). According to the previous investigation [15], heating demand of the building stock in Stockholm will decrease in the future; e.g. during 2081-2100 it will be 25-30% less than the demands before 2011. However, climate uncertainties play an important role in the assessment. For example, in the case of having different GCMs, there can be differences up to 30 kWh/m2 (relatively around 30%) in the 20-year mean values. Moreover, variations of the heating demand (hourly standard deviations) can reach to values more than 50% of the average heating demand with 25-30% uncertainties due to different GCMs. Uncertainties increase for cooling demand up to 500%, however the calculated cooling demand for future is still low in Stockholm. Among all the uncertainty factors of the climate data, different GCMs introduce the largest uncertainties in the calculations. For more details about modelling and assessing the future energy performance of the building stock in Stockholm the reader is referred to [15] and [17].

4. Future climate scenarios

The weather data sets which are used in this work were generated by RCA3, the third generation of the Rossby Centre regional climate model [5]. The two considered climate scenario are generated by two different GCMs of CNRM and ECHAM5, both forced by A1B scenario of the Special Report on Emissions Scenarios (SRES) [20]. Approximate carbon dioxide equivalent concentrations, corresponding to the computed radiative forcing due to anthropogenic greenhouse gases and aerosols in 2100, for the SRES A1B scenario is about 850 ppm [21] (for more details the reader is referred to [8] and [22]). All the RCM weather data were synthesized in Matlab before being used in energy simulations. For example climate parameters were synchronized and shortwave components of the solar radiation were calculated (for more details the reader is referred to [22]).

5. Results

Energy performance of the building stock in Stockholm for future climate has been discussed thoroughly previously [15,17] and this section mainly evaluates the application of the synthesized weather data on calculating the hourly energy demand when a group of buildings with different properties are considered. Energy simulation results for the building stock in Stockholm are examined here when the synthesized weather data sets are made out of two different climate scenario: RCA3-CNRM-A1B3 and RCA3-ECHAM5-A1B3.

For the case of simulating the building stock using the original weather data sets, 153 buildings were simulated for 30 years for two climate scenarios, resulting in 9180 simulation years per period. Results are shown as light grey lines in Fig. 1 and Fig. 2, which the first figure shows the cumulative heating and cooling demand and the latter hourly profiles of the heating demand. Hourly averages of the light grey lines are shown as dark grey lines. Using TDY, ECY and EWY data sets decreases the number of simulations to 459 per period (20 times less than the original case). In both Fig. 1 and Fig. 2, TDY covers the most probable area of results (compared to the original case), while ECY results in having the highest heating demand and the lowest cooling demand, in contrary to the results out of using EWY. It is interesting to see how much cooling demand can increase by time in Fig. 1 using the EWY. However, the two extremes define the pessimistic boundaries and the probability of getting such conditions and cumulative distributions as Fig. 1 is very low since the worst conditions do not happen continuously for one year. Extreme conditions will happen but not continuously and usually during short time periods which will be more often and stronger for future climate. Having a general picture about their probability, such as Fig. 3, helps in resilient design of buildings and energy systems. Boxplots in Fig. 3 compare the distribution of the heating and cooling power for five different cases which “All years” corresponds to the original case “Triple” to the case of considering all TDY, ECY and EWY together. TDY and Triple have quite similar distributions to the original case. For the considered building stock with several climate scenarios, considering extremes in calculations (Triple case) results in a closer distribution to the original case as it is obvious in Fig. 3 by comparing “All years” and “Triple”. This means we can reach to distributions very similar to the original RCM data by running energy simulations only for three years instead of 60 years per building.

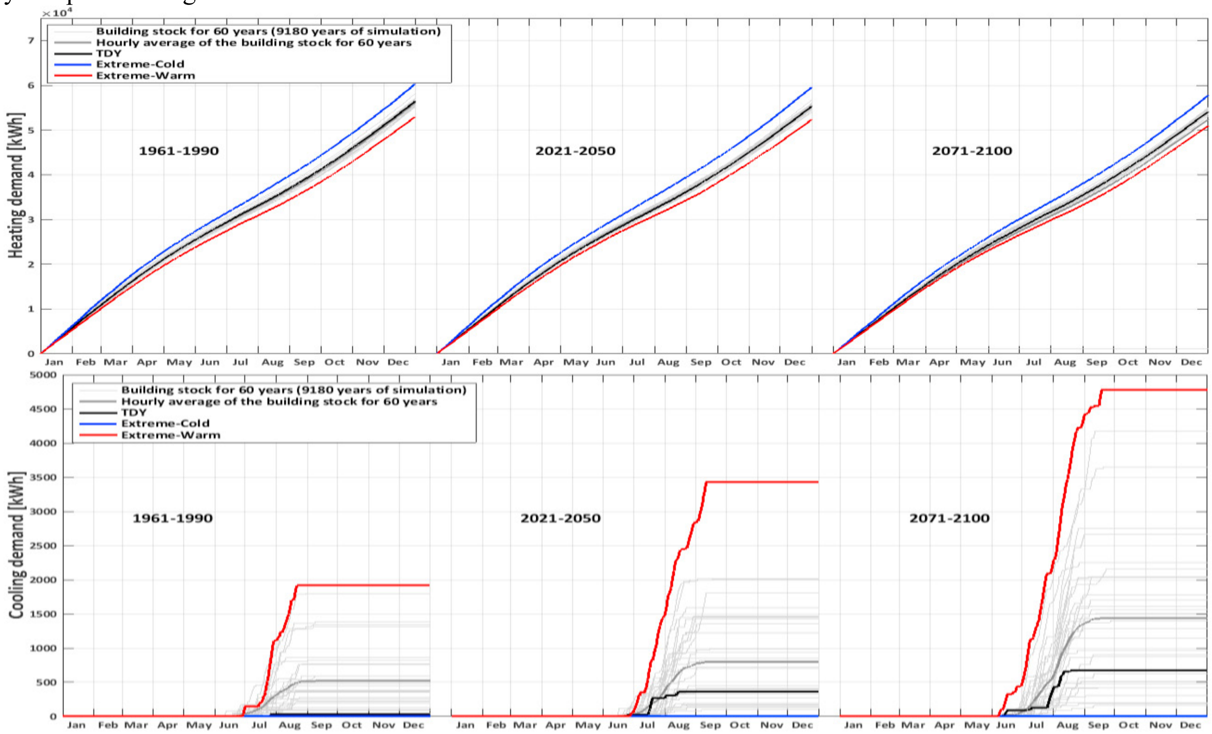
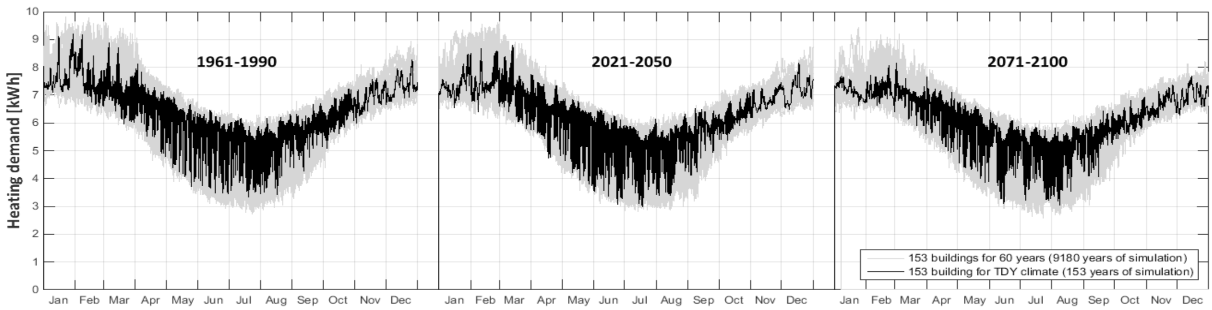


Fig. 1. Cumulative heating (top) and cooling (bottom) demand for simulations using 9180 years of weather data (light grey), hourly average of them (dark grey) as well as one year of synthesized TDY (black), ECY (blue) and EWY (red) weather data when two climate scenarios are considered.



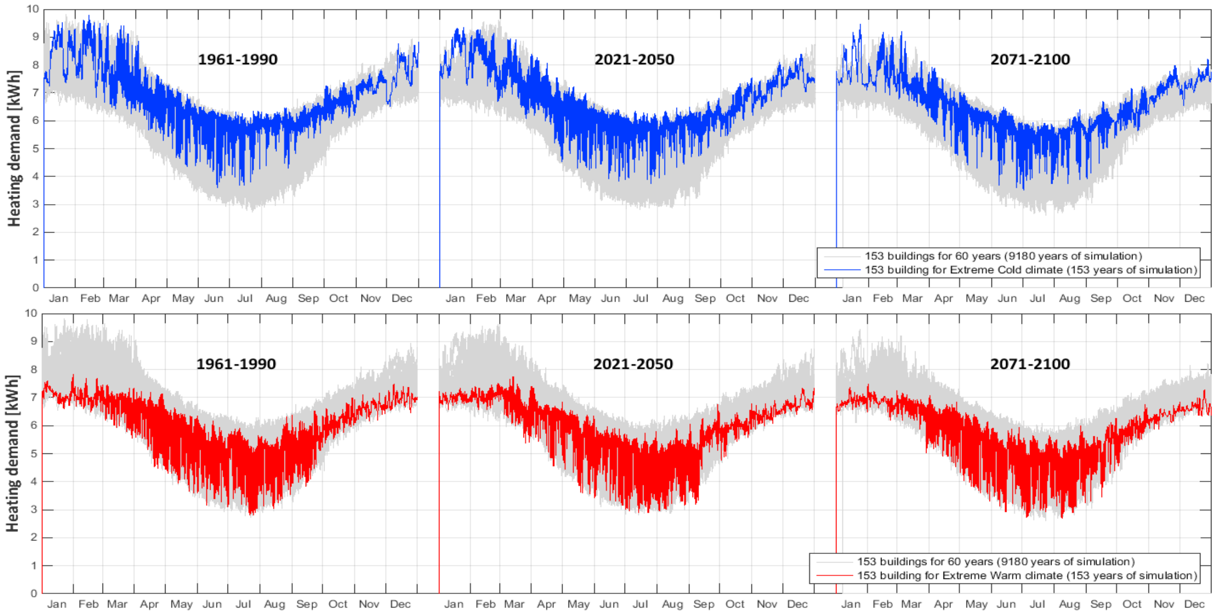


Fig. 2. Hourly profiles of heating demand for 9180 years of simulations (light grey lines) and (from top to bottom): 1) TDY, 2) ECY and 3) EWY. The considered case is the building stock in Stockholm with two climate scenarios (RCA3-CNRM-A1B3 and RCA3-ECHAM5-A1B3).

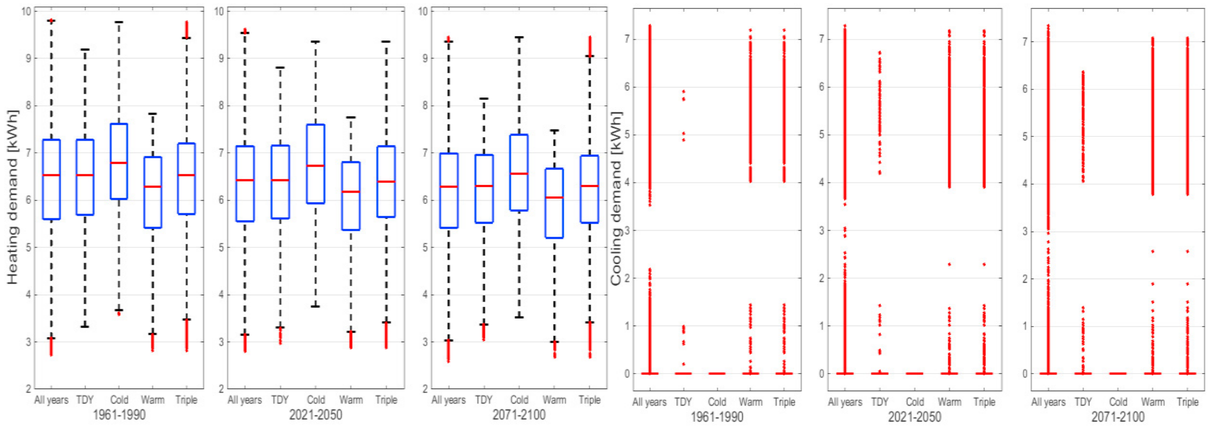


Fig. 3. Boxplots for the hourly heating (left) and cooling (right) demand of 153 buildings for 30 years and two climate scenarios (All years – equal to 9180 year-simulation), TDY for all buildings and all scenarios (TDY – equal to 153 year-simulation), ECY for all buildings and all scenarios (Cold – equal to 153 year-simulation), EWY for all buildings and all scenarios (Warm – equal to 153 year-simulation) and the combination of TDY, ECY and EWY (Triple).

6. Conclusions

This work suggested a method for synthesizing representative weather data sets out of regional climate models (RCMs) for performing the impact assessment of climate change on buildings. The method suggests synthesizing three weather data sets for each 30-year period, representing typical (TDY) and extreme conditions (ECY and EWY). Each weather data set is created based on comparing the cumulative distribution of the outdoor (dry-bulb) temperature and finding the typical and extreme months. The three weather data sets can be synthesized based on one climate scenario or more than one. In the case of the latter, climate uncertainties will be covered and the synthesized data represent all the considered scenarios.

According to the results, it is possible to use the synthesized weather data sets in the energy simulations and produce reliable results, representing the cumulative energy distributions as well as the hourly variations. The cumulative distribution of the heating and cooling demand using TDY are very similar to the original weather data set. Moreover, the hourly profiles of temperature, heating and cooling demand are represented with their natural hourly variations, using the three synthesized data sets; hourly profiles by TDY represent the most probable conditions while ECY and EWY define the extreme conditions which can be considered for the resilient design of buildings and energy systems. Distributions of the hourly heating and cooling demand were compared among different data sets, using boxplots. According to the results, considering TDY, ECY and EWY together (Triple) results in having estimations very similar to the cases where the original weather data sets are used.

Using the suggested synthesized weather data sets has the advantage of decreasing the number of simulations extensively while it does not neglect extreme conditions which will happen more often in future. Moreover, by considering several scenarios in synthesizing the weather data sets, it is possible to have a scientifically valid assessment while keeping the number of simulations much lower than working with the original RCM data sets.

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