Development of Climate Change Adapted Weather Files for Building Performance Simulation: Implications for Southeast Asia

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Abstract: *In its 4th assessment report the Intergovernmental Panel on Climate Change (IPCC) has concluded that there is a strong evidence of a global warming trend affecting average air and ocean temperatures. Based on this evidence a growing number of studies on the impact of climate change on various aspects of human society are being conducted. The construction industry however, appears to be ill prepared for the challenges of a changing climate. Current weather files for building performance simulation are typically derived from historical weather data of the time period 1961-1990, which does not reflect recent climate trends, let alone future climate predictions. Therefore, there is a risk that current building designs may not be viable for the future, compromised by their design approach and building services strategy. This paper presents a method for adapting current industry standard weather files in the EnergyPlus/ESP-r format (EPW) to incorporate climate change predictions. It is based on output of the HadCM3 general circulation model (GCM), with the existing EPW weather files being effectively 'morphed' with mean changes predicted by the HadCM3 model with respect to the 1961-1990 'baseline' period. Regional and temporal downscaling of the coarse GCM data is achieved through the 'present-day' EPW weather files. A tool is presented that permits generation of such climate change adapted weather files for any location in the world from readily available GCM and EPW data. Comparisons of climate change weather data generated using this method with local long term trends as well as regional IPCC predictions show a reasonable fit for the tropical climates of Southeast Asia. This gives confidence that the resulting climate change adapted EPW files can be applied for building performance simulations in Southeast Asian climates in order to assess the viability of a particular design approach or building services system for the anticipated future climates.*

Keywords: climate change, weather data, long term climate trends, building performance simulation, impact analysis

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) has identified human activity as a significant cause for the observed changes in the global climatic conditions since 1750 [1, 2]. There is strong evidence that anthropogenic emissions of carbon dioxide, methane, nitrous oxide and halocarbons etc have changed the balance of incoming and outgoing radiation to the Earth's atmosphere resulting in a net increase of the incoming radiation [2]. Furthermore, it has been found that the anthropogenic greenhouse gas emissions outweigh reductions of incoming solar radiation caused by human emissions of aerosols into the atmosphere. In its 4th assessment report (AR4) the IPCC highlights a net 'positive global radiative forcing' of between 0.6 W/m² to 2.4 W/m².

The observed positive global radiative forcing has resulted in a rise of the global average temperature levels as shown in Figure 1 for the years 1914 to 2007 for the case of England. This data which has been determined by the UK Met Office [3] by using historical weather station data as well as GIS regression and interpolation methodologies [4] shows a linear rise of the annual mean temperature of 0.94 °C over the given time period. This is a stronger trend than the 0.74 °C average global mean temperature rise given by the IPCC for the last 100 years (1906-2005) [2]. Furthermore, as can be seen in Figure 1 an accelerated temperature rise has been observed for the past two decades over England. However, temperature trends are not equal for all regions of the world. This is shown in Figure 2 which highlights the trends for both, the United Kingdom (UK) and Thailand for the last 50 years (1958-2007). Whilst the Thailand data, which has been derived by the authors from monthly long term data published by the Food and Agriculture Organization of the United Nations [5] [1], shows a clear increase in annual mean temperature levels, the magnitude is slightly less than for the UK. However, due to the higher general temperature levels in Thailand and the smaller annual swing in the monthly mean temperatures (Figure 3), the implications of the temperature increase are potentially more severe for society than in the UK. Figure 4 highlights the annual mean temperature deviation from the current meteorological baseline climate (1961-1990) over the last 50 years for both countries. It can be seen that, for the last two decades, the UK has experienced a more significant warming trend. However, the overall warming trend is also clearly visible for Thailand.

[1] The number of weather stations in this data set varies (28 in 1958, 71 in 2007). Furthermore not all stations delivered data continuously. A monthly weighting has been introduced for deriving the annual mean temperatures in order to account for different station numbers throughout the year. However, no regional weighting or statistical analysis has been conducted. Therefore, the data is indicative only.

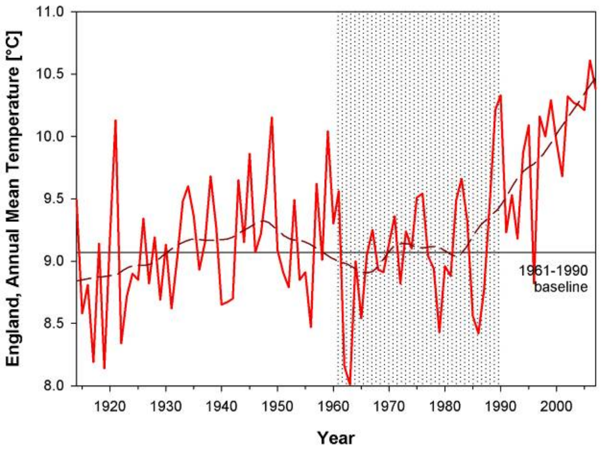

Fig. 1 England 1914-2007 annual mean temperatures in relation to the 1961-1990 baseline mean (Data source: Met Office [3]).

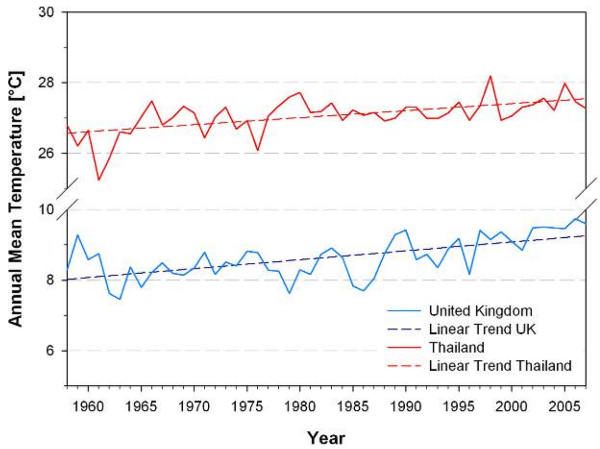

Fig. 2 Thailand and UK 1958-2007 annual mean temperatures with trend lines (Data source UK data: Met Office [3], data source Thai data: United Nations [5]).

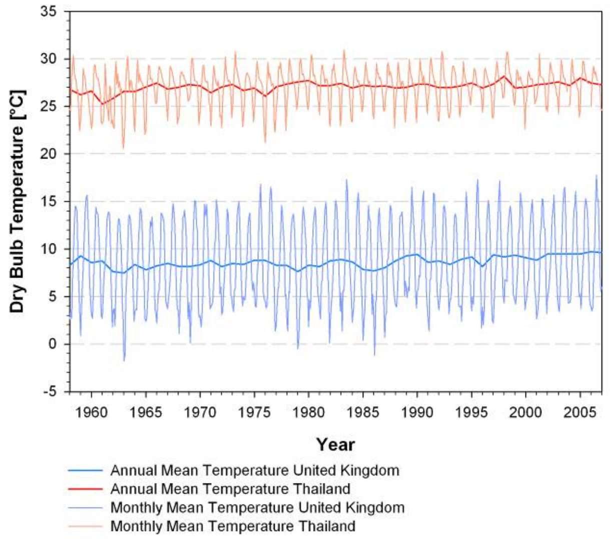

Fig. 3 Thailand and UK 1958-2007 monthly and annual mean temperatures (Data source UK data: Met Office [3], data source Thai data: United Nations [5]).

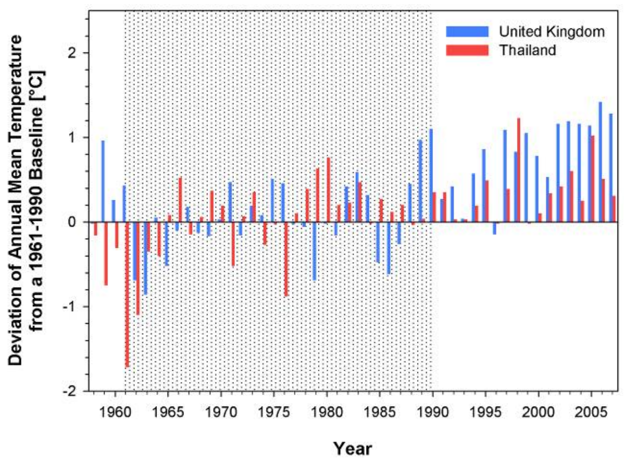

Fig. 4 Thailand and UK deviation of annual mean temperatures from the 1961-1990 mean (Data source UK data: Met Office [3], data source Thai data: United Nations [5]).

The current climate trends and their future projections have strong implications for many aspects of human life. However, whilst there are a number of reports giving detail on the potential impacts of climate change and strategies for climate change mitigation [6, 7, 8], uptake of climate change issues appears to be slow in the building industry and awareness of the potential threats to buildings and urban areas rather limited. One reason for this can be seen in the lack of readily available climate change weather data that could be used by the building industry in standard tools such as building performance simulation programs. The aim of this paper is to bridge this gap.

2. METHODOLOGY

2.1 Weather files for building performance simulation

Building performance simulation is one of the most widely applied tools for predicting building performance and to appropriately size heating, ventilation and air-conditioning (HVAC) systems prior to construction. There are a number of software packages available to end users that can be used to assess building designs at various stages of the design process [9]. These tools require annual weather data sets for their simulations which should ideally be derived from local climatological data. However, for many countries the number of available files is rather limited. Data formats common to most software packages are the Typical Meteorological Year (TMY2) and the EnergyPlus/ESP-r Weather (EPW) data formats [10]. Typically, these files are derived in a statistical approach from long-term measured datasets, preferably from the meteorological baseline years 1961-1990 [11]. However, due to the timeframes used for their generation, many of these files do not include the most recent climate trends. Therefore, they are often not well suited to accurately simulating building performance under current climate conditions, let alone the potential future climate. However, as new buildings are evidently designed for the future, future simulation weather data series are of a key importance to the building industry.

2.2 Available climate change weather data series

Generating weather data that integrates climate change predictions into industry standard weather file formats ideally requires accurate climate change prediction data from Regional Climate Models (RCM) at a small grid scale (e.g. 50 km). However, the availability of such data is limited. Furthermore, RCMs generally only include selected regions of the world and often do not cover all the parameters required for building performance simulations. Yet, the scope of this study was to generate weather files from world-wide data that is readily available in the public domain. Therefore, General Circulation Model (GCM) data that can be accessed via the IPCC Data Distribution Centre [12] was reviewed for this purpose as this data covers world-wide locations, yet at a coarser data grid of typically between 1 to 5 degrees in latitude and longitude. An example of such a GCM data grid can be seen in Figure 5 below over parts of Southeast Asia for the UK Met Office Hadley Centre coupled model version 3 (HadCM3) which uses a 2.5 degree grid in latitude and a 3.75 degree grid in longitude [12]. Summary data from this GCM was used for this study. The selected HadCM3 data, which was generated for the IPCC's 3rd Assessment Report (AR3) [1], represents 3 independent simulation experiments of the so-called A2 emissions scenario [13]. The dataset has been chosen as it appeared to be the most suitable dataset for the purpose of this work, the reasons being that:

a) all the key parameters required for simulation weather files are contained in at least one of the 3 GCM experiments,
b) the A2 emissions scenario represents a 'business as usual' case for the global development of human emissions [13] and, therefore, in the opinion of the authors, can be considered as 'likely' future development,
c) more than one HadCM3 A2 GCM experiment is available which permits deriving average values from the weather data predictions for individual model grid points,
d) the 3 HadCM3 A2 experiments were also the basis for a UK RCM that has been previously used for generating regional climate change adapted weather files [10, 14, 15].

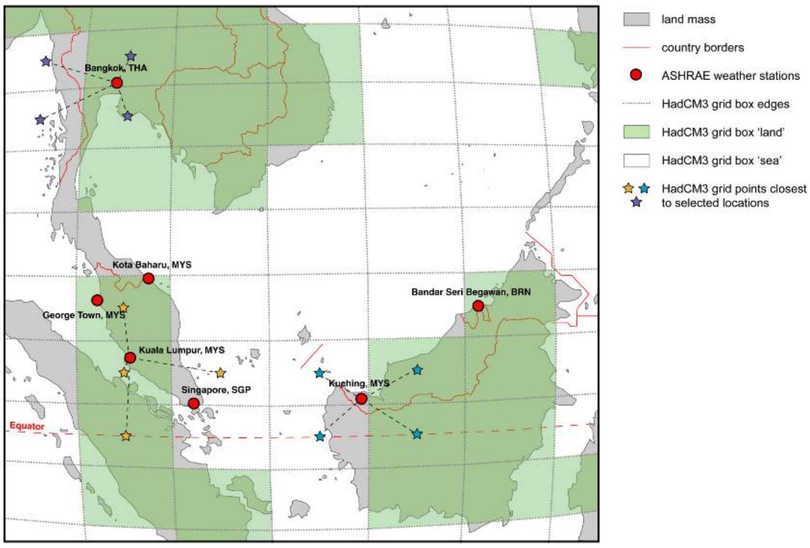

Fig. 5 HadCM3 general circulation model data grid over parts of Southeast Asia with selected weather stations in Brunei, Malaysia, Singapore and Thailand: location of the four closest grid points of the weather stations Bangkok, Kuala Lumpur and Kuching (Data source grid points: HadCM3 summary data – IPCC Data Distribution Centre [12], data source weather data: U.S. Department of Energy, Energy Efficiency and Renewable Energy [16].

2.3 'Morphing' of present-day weather data

The HadCM3 A2 summary data is provided by the IPCC Data Distribution Centre [12] as monthly values for each grid point of the HadCM3 data grid (Figure 5) for a simulated 1961-1990 baseline climate and for three future time slices, the 2020's, 2050's and 2080's. However, monthly data is not suited for use in building performance simulation where hourly data is required. Therefore, this data needs to be transformed into hourly time series. This is achieved by applying the so-called 'morphing' methodology originally developed by Belcher, Hacker and Powell [15] for UK RCM model results. In this method, the climate change simulation results are superimposed on existing hourly weather data series, in this case EPW weather files, to produce a climate change adapted weather data set [10, 15]. The advantage of this method is that the EPW weather data, which has been derived from long-term measurements, delivers spatial and temporal downscaling of the coarse GCM data. According to recommendations given by the IPCC [17] the average values of the four HadCM3 grid points closest to the point of interest, i.e. the EPW weather station, are used for the 'morphing' procedures. This is highlighted in Figure 5 for the weather stations of Bangkok, Kuala Lumpur and Kuching.

In order to make the results of this work available to the building industry a Microsoft® Excel based software tool has been developed which permits individual generation of climate change adapted EPW weather files for any location on the world for the A2 emissions scenario and the 3 future time slices of the 2020's, 2050's and 2080's [18]. This tool, which is shown as a screenshot in Figure 6, is available free of charge. However, users need to obtain the required HadCM3 A2 scenario data [12] and a 'present-day' EPW file, both of which are readily available in the public domain.

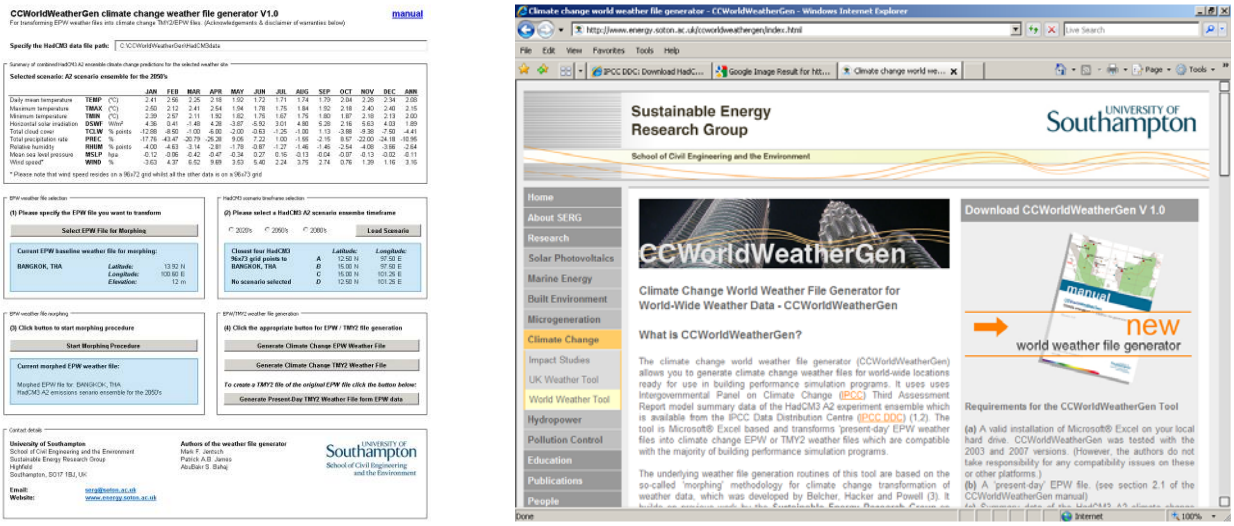

Fig. 6 Screenshot and download page of the climate change weather file generator tool (CCWorldWeatherGen) for creating future weather files in EPW/TMY2 format from HadCM3 GCM A2 scenario ensemble data [18].

3. RESULTS AND DISCUSSION

3.1 Climate change adapted weather data for Bangkok

The ASHRAE EPW weather file for Don-Muang Airport in Bangkok, which can be downloaded from the U.S. Department of Energy website [16], has been selected for further investigation within this study. Figure 7 shows the monthly mean temperature of the original EPW weather file compared to climate change adapted versions of this weather data for the 2020's, 2050's and 2080'. A clear rise in average dry bulb temperatures can be seen from one time step to the next, resulting in a predicted temperature rise of about 4 °C from current levels to the end of the 21st century.

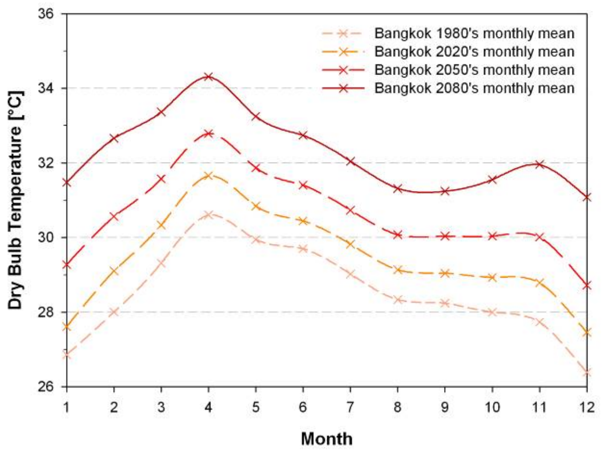

Fig. 7 Bangkok, monthly mean temperature, 'present-day' and 'morphed' ASHRAE EPW weather data.

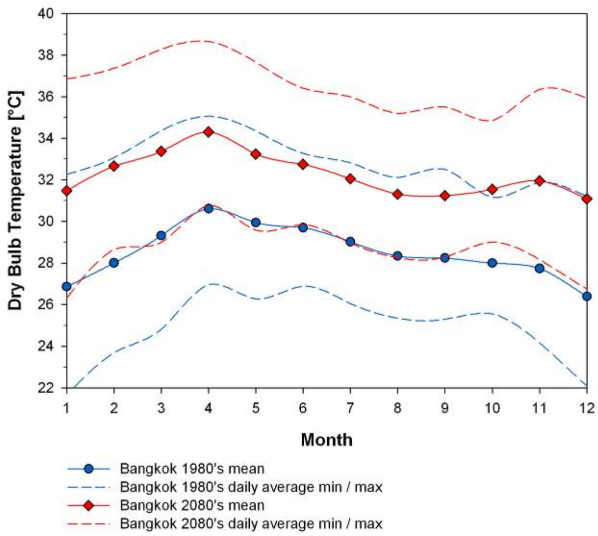

Fig. 8 Bangkok, ASHRAE EPW data, comparison of monthly average daily mean, minimum and maximum temperatures for the 1980's and the 2080's.

This increase can be considered as very significant for living conditions in urban areas like Bangkok which also suffer from urban heat island effects further exacerbating the implications of climate change. Figure 8 highlights that the present-day monthly mean temperatures can be expected to be similar to the 2080's monthly average daily minimum temperatures whilst today's monthly average daily maximum becomes the mean in the 2080's. As a result of the rising temperatures the relative humidity is expected to drop over time by a total of about 5 percentage points in the 2080's from today's values (Figure 9). Interestingly, the temperature increase shown in the analysed data is not linked to a corresponding increase in solar radiation. As can be seen in Figure 10 the monthly mean daily global horizontal radiation is predicted to rise marginally only over time, with the only significant change being a 5.5 % increase from today's value in November in the 2080's. In particular, the two hot months of April and May show no relevant change. Furthermore, some months like May and June even show a gradual solar radiation decrease of up to 3.5 %. This implies that the temperature increase described above is largely driven by changed global climate conditions and changes in local rainfall patterns. This is supported by the average monthly precipitation data of HadCM3 A2 experiments for the four grid points used for the Bangkok climate change weather files. According to this data precipitation is predicted to reduce significantly outside the monsoon season and increase slightly during the monsoon season (May to October). [2]

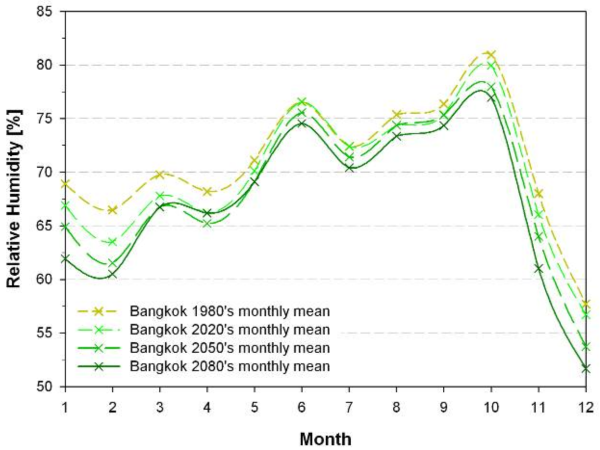

Fig. 9 Bangkok, monthly mean relative humidity, 'present-day' and 'morphed' ASHRAE EPW weather data.

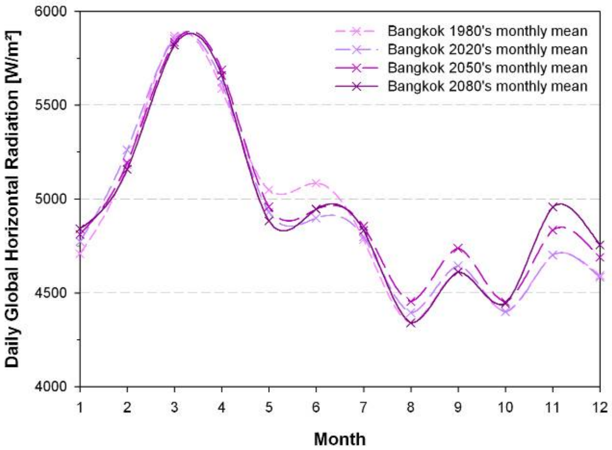

Fig. 10 Bangkok, monthly mean daily global horizontal radiation, 'present-day' and 'morphed' EPW weather data.

3.2 Comparison of climate change weather data with long-term trends and regional IPPC predictions

For data evaluation purposes the future climate data discussed above has been compared to long-term measurements for Don-Muang Airport [5] [3]. Figure 11 shows the long-term annual mean temperatures from 1958 to 2007 in comparison to the annual mean values of the 4 investigated EPW weather files. It can be seen that the 'present-day' EPW file, which contains data of the years 1983 to 1999, corresponds well to the annual data of the corresponding years. However, when comparing the linear trend of the long-term temperature measurements with the climate change adapted weather data, it can be seen that the warming process is predicted to accelerate over time.

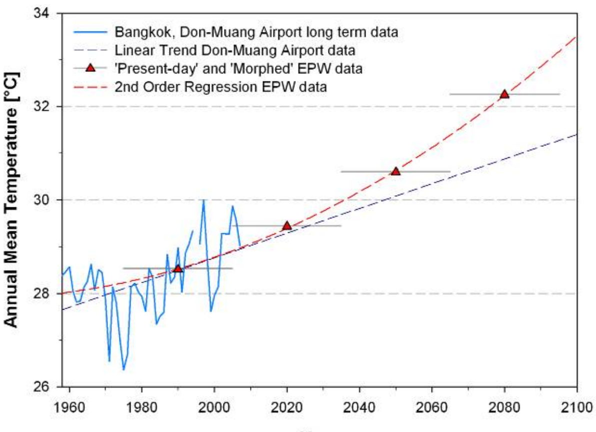

Fig. 11 Bangkok, Don-Muang Airport, comparison of long term measured annual mean temperature with 'present-day' and 'morphed' ASHRAE EPW data (Data source long term data: United Nations [5], data source EPW data: U.S. Department of Energy [16], data source climate change data: HadCM3 – IPCC Data Distribution Centre [12],).

[2] The ASHRAE EPW file for Bangkok does not contain precipitation data. Therefore, the 'morphed' files do not include any precipitation data either.
[3] No data was available for the years 1958-1969 and 1972. For these years data from WMO station 48455 (Bangkok) was used. 1995 data is missing.

In addition, the climate change temperature projections shown in Figure 11 fit reasonably well with the combined IPCC GCM A2 emissions scenario predictions for the region of Southeast Asia which predict a regional temperature increase of about 3.5 to 6 °C from the 1961-1990 baseline by the end of the 21st century [2]. However, the projections presented here are clearly at the upper end of these predictions, the reasons for this most probably being that the Don-Muang EPW baseline data is slightly out of phase with the IPCC baseline and that the measured EPW data will contain urban heat island effects of the greater Bangkok area which are not included in GCM data.

4. CONCLUSIONS

From the above analysis of the climate change adapted Bangkok EPW weather data it can be concluded that, for Southeast Asian climates, the 'morphing' approach presented here is well suited for transforming 'present-day' weather data into climate change weather data. Furthermore, it becomes evident that climate change adapted versions of weather files widely used within the building industry should be used for current building design projects in order to evaluate the building's potential future performance and appropriately dimension HVAC facilities.

5. ACKNOWLEDGMENTS

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