Climate Change adapted simulation weather data: implications for cities in hot, arid climates of the Middle East

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Abstract
Climate change represents a significant challenge for human settlements and buildings which may fail to perform under the predicted future higher summer temperatures. This is the case in particular for the hot, arid climates of the Middle East where the Intergovernmental Panel on Climate Change projects an average summer temperature rise of between 2.5 and 5 °C by the end of the 21st century for an emissions scenario assuming a mix of fossil fuel intensive and non-fossil energy sources. Therefore, it is becoming increasingly important to assess the future building performance and the associated cooling loads during the summer months. However, data suitable for this purpose is scarce. This paper presents a tool for transforming existing industry standard weather data for building performance simulation into climate change adapted weather data using climate model outputs generated by the UK Hadley Centre. Weather data generated with this tool is investigated for selected cities in the Middle East with a specific focus on the potential future cooling load requirements.

Keywords: Middle East, climate change, weather data, building performance simulation, cooling load

1. Introduction
Buildings and their associated services are typically designed for a specific location based on historic knowledge of the prevailing climate. However, anthropogenic emissions of carbon dioxide, methane, nitrous oxide and halocarbons etc have led to a changed balance of incoming and outgoing radiation to the Earth's atmosphere resulting in a net global warming effect that can be expected to increasingly impact on building performance. Over the past 100 years (1906-2005) a rise of 0.74 °C in global mean temperature has been observed and, depending on future emissions of greenhouse gases, the Intergovernmental Panel on Climate Change (IPCC) projects a further 1.1 - 2.9 °C to 2.4 - 6.4 °C temperature rise towards the end of the 21st century relative to a 1980-1999 baseline [1]. Furthermore, the global warming trend has been observed to accelerate over the past decades with the linear trends from 1956-2005 and 1981-2005 given as 0.64 °C and 0.44 °C respectively [1].

However, temperature trends are regionally diverse. For the Middle East the linear trend of annual mean temperatures form 1901-2005 varies significantly between an observed rise of 0.2 - 0.5 °C for the Mediterranean areas, 0.5 - 1.1 °C for the Persian Gulf and 1.4 - 1.7 °C for central regions in eastern Iran [1]. Figure 1 shows the deviation of the annual and the summer mean temperatures from the long-term mean (1961-1990) over the entire region since 1870. This data has been extracted from the global CRUTEM3 dataset on a 5° by 5° grid basis [2] and spans the 32 grid boxes representing the Middle East. As can be clearly seen in Figure 1, the last 25 years highlight a strong warming trend in the Middle East which is particularly significant during the summer months (June, July, August). Prior to this no specific trend can be determined. However, it needs to be noted that data prior to the 1940s covers less than half of the grid points representing the region (Figure 1). Multi-model simulations under the A1B emissions scenario which assumes a mix of fossil fuel intensive and non-fossil energy sources [3] predict a further annual temperature rise over the region of between 2.5 and 5 °C by the end of the century relative to a 1980-1999 baseline. In keeping with the data shown in Figure 1, a stronger effect is predicted during the summer months, particularly in central areas of the Arabian Peninsula and inland areas of Turkey, Syria, Iraq and Iran [1].

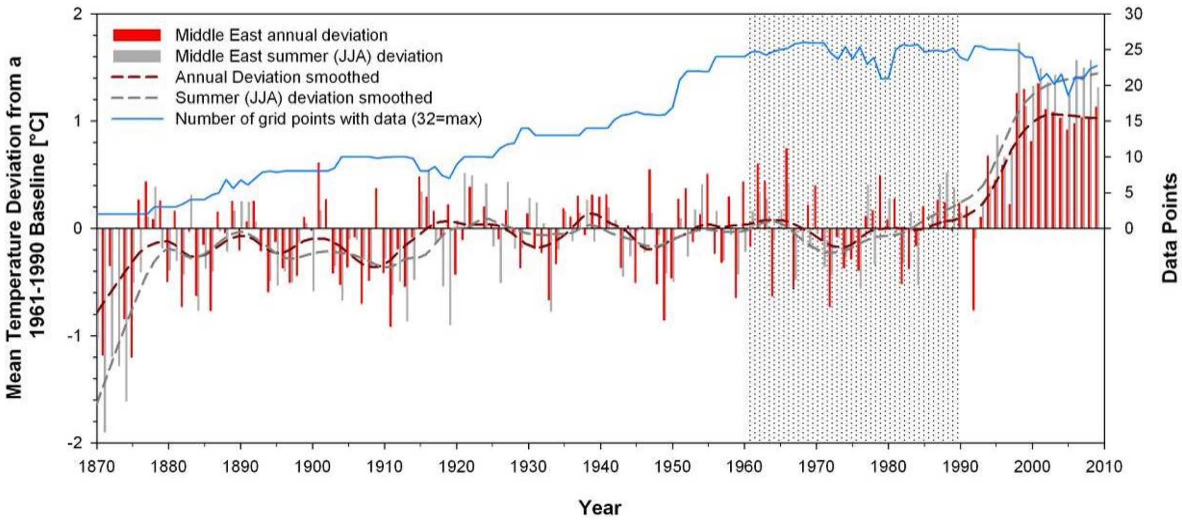

Figure 1 – Deviation of the annual and summer mean temperatures from the 1961-1990 mean for the Middle East (Data source: Climatic Research Unit [2])

Most research considering climate change implications for the Middle East relates to projected changes in precipitation [4,5,6] which according to multi-model simulations under the A1B emissions scenario is predicted to fall by up to 30% towards the end of the century in many parts of this already water-scarce region [1]. Only the southern parts of the Arabian Peninsula spanning the United Arab Emirates, Oman, Yemen and the southernmost part of Saudi Arabia are predicted to see some increase in annual rainfall [1]. However, this paper focuses on the implications of climate change for buildings and urban areas in the region as there is currently a lack of such assessments, albeit the potentially adverse impacts of a warming climate on cooling energy consumption in buildings and the habitability of highly urbanised areas. One reason for this is likely to be the limited availability of appropriate data, the generation of which is discussed in the following.

2. Methodology

2.1 Generation of climate change adapted weather data

The performance of buildings and urban areas is typically assessed with standardised weather data in hourly format. Commonly used data formats are the Typical Meteorological Year 2 (TMY2) or EnergyPlus/ESP-r (EPW) formats [7, 8]. TMY2/EPW data is freely available on the web [9] or can be generated with tools such as Meteonorm [10] which create hourly time series from long term means [11]. Such weather files are commonly used within the building industry to plan heating, ventilation and air-conditioning (HVAC) systems. However, as the data is derived from historic weather series it is not suited for predicting performance changes induced by future changes to the climate. To address this issue Belcher et al [12] have developed a methodology for transforming present-day weather data into future time series. This method, which is commonly termed 'morphing', superimposes the projected monthly changes of climate models on hourly present-day data by either multiplying it with a fractional change, adding an absolute change or using a combination of the two [12]. It was originally developed for the United Kingdom (UK) to transform regional climate model (RCM) outputs of the UKCIP02 model series [13] into climate change adapted weather series. The 'morphing' approach is very attractive for the building industry as it permits a direct comparison of the resulting files with the original dataset. It is currently the most widely used method for generating future weather series for the building industry [14]. However, a disadvantage is that potential changes to the frequency or extent of extreme weather events are not captured in the generated data [12].

Producing 'morphed' weather data for locations in the Middle East would ideally require detailed regional climate model outputs similar to the UKCIP02 data. However, similar to other regions of the world, such data is not readily available in the public domain. Therefore, outputs from general circulation models (GCM) available from the IPCC Data Distribution Centre [15] were reviewed for this purpose, as they span the whole world yet at a coarser gird scale than RCMs. Of the data provided by the IPCC only the three model runs of UK Met Office Hadley Centre coupled model version 3 (HadCM3) for the A2 emissions scenario (medium-high emissions) contain all the parameters required for producing ‘morphed’ weather files. Therefore, this data was selected for transforming present-day EPW files into future weather series using the same calculation routines as in the previous work conducted for the United Kingdom (UK) [16]. A Microsoft® Excel based software tool has been developed that allows individual end user generation of climate change adapted weather files [17]. This tool which is shown as a screenshot in Figure 2 permits generation of ‘morphed’ weather files in the EPW/TMY2 formats for the A2 emissions scenario under 3 future time slices, the 2020s, 2050s and 2080s. It has been made available as download and requires a present-day EPW file and the HadCM3 A2 model results as inputs, both of which can be downloaded from the internet [9, 15].

2.2 Data for assessing climate change implications on urban areas in the Middle East

The tool discussed above was used to generate ‘morphed’ weather data for 8 locations throughout the Middle East. These are shown in Figure 3 which also details the HadCM3 data grid over the region and gives the four closest grid points to each location. In accordance with recommendations by the IPCC, average values of the three HadCM3 A2 model runs for these four grid points were used as inputs for the ‘morphing’ calculations [18]. The present-day EPW files for the locations were obtained from the U.S. Department of Energy [9] and mostly stem from the IWEC dataset with the data for Kuwait and Tehran being from the KISR and the ITMY datasets respectively (Table 1). ‘Morphed’ weather files were produced for all the three future time slices (2020s, 2050s, 2080s). Changes to dry bulb temperature, relative humidity, global horizontal radiation and wind speed were analysed as these parameters have the most immediate impact on the performance of buildings and cities. However, it needs to be noted that the data sampling periods of the present-day datasets differ from the baseline used for the HadCM3 predictions (1961-1990) which means that climate change implications are potentially overestimated [12, 16]. This is in particular the case for the Tehran data (1992-2003).

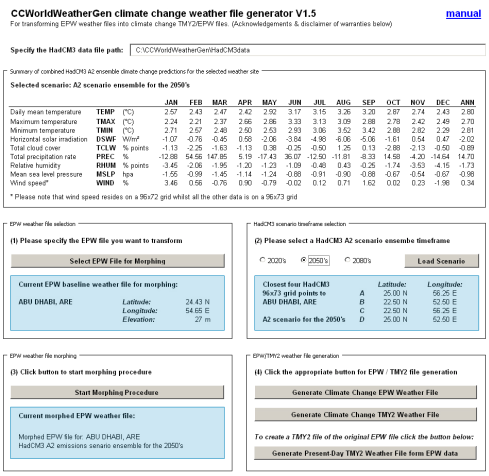

Figure 2 – Screenshot of the CCWorldWeatherGen tool for generating climate change adapted weather files in EPW/TMY2 format from current EPW files and HadCM3 GCM A2 data [17]

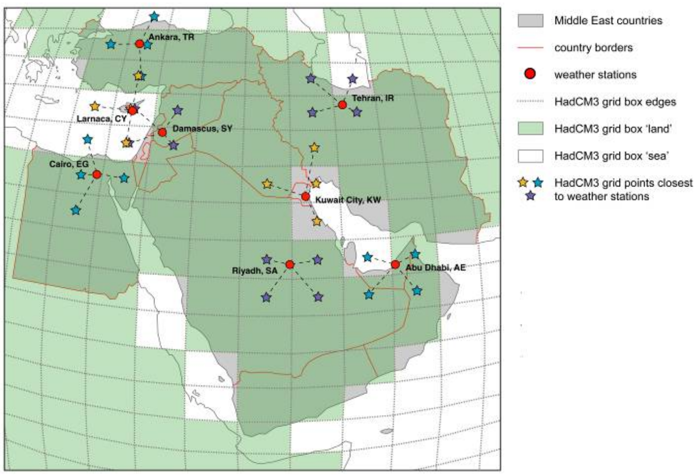

Figure 3 – HadCM3 data grid over the Middle East with selected weather stations including the four closest grid points to these stations (Data source grid points: HadCM3 summary data – IPCC Data Distribution Centre [15], data source weather data: U.S. Department of Energy [9])

In addition to the above the predicted future annual means for the dry bulb temperature at the given locations were compared to long-term mean data in order to investigate the magnitude of the predicted changes in relation to the temperature trends observed at the given sites. Monthly mean data provided by the Food and Agriculture Organization of the United Nations was used for this purpose [19]. Table 1 highlights the data availability as well major gaps in the data. Where available, gaps were filled with mean temperature values derived from the corresponding monthly average daily maximum and minimum temperatures. These calculated values were adjusted using the long-term average difference between measured and calculated monthly mean temperatures. As a second measure gaps were filled with mean temperature data from the closest weather station, again using values adjusted with the long-term average difference between the two stations. However, this was only undertaken in cases where this difference was within reasonable limits. For a limited number of months and only if no data was available average monthly values of the preceding five years were used.

Table 1 – Location details and long-term data availability of the 8 investigated weather stations

Weather station	WMO no.	Lat. [°N]	Long. [°E]	Alt. [m]	EPW source (time frame)	Monthly long term temp. data	Comments long term temp. data
Abu Dhabi Internat. Airport	41217	24.43	54.65	27	IWEC[1] (1983-1999)	11/1979-12/2008	Not enough long term data
Ankara Esenboga	17128	40.12	32.98	949	IWEC (1982-1999)	01/1973-12/2008	Not enough long term data, difference to Ankara Central (WMO 17130) too large
Cairo	62366	30.13	31.40	74	IWEC (1982-1999)	01/1950-12/2008	04/1961-06/1966 missing - filled with Helwan (WMO 62378), major gaps 1975-1991 filled with min/max averages
Damascus Internat. Airport	40080	33.42	36.52	605	IWEC (1982-1999)	01/1973-12/2008	1951-1972 filled with Damascus-Mezze, otherwise minor gaps only
Kuwait Internat. Airport	40582	29.22	47.98	55	KISR[2] (1986-1997)	01/1956-12/2008	1990-1991 missing completely, otherwise minor gaps only
Larnaca Airport	17609	34.88	33.63	2	IWEC (1982-1999)	03/1977-12/2008	1950-1972 filled with Nicosia (WMO -) unadjusted, 1973 -1977 filled with Akrotiri (WMO 17601)
Riyadh	40438	24.72	46.72	612	IWEC (1982-1999)	08/1951-12/2008	Major gaps 1981-1991 filled with min/max averages
Tehran Mehrabad	40754	35.68	51.32	1191	ITMY[3] (1992-2003)	01/1951-12/2008	1981-1989 missing completely, major gaps 1975, 1978-1980, 1990-1991 filled with min/max averages

[1] International Weather for Energy Calculations (IWEC)
[2] Kuwait Institute of Scientific Research (KISR)
[3] Iranian Typical Meteorological Year (ITMY)

3. Results and Discussion

3.1 Future climate risks for cities in the Middle East

For all investigated weather stations a clear rise in temperature over time was determined. However, the magnitude was observed to be greater for more inland stations than coastal regions. Furthermore, the rise in summer temperatures was observed to be greater than the rise in winter temperatures. The most pronounced changes were determined for Ankara where the July/August mean temperatures in the 2080s are predicted to be higher than the present day maximum temperatures (Figure 4). Furthermore, the daily global horizontal radiation is predicted to increase significantly over the summer months (by ~1500 W/m² in July) whilst the relative humidity reduces notably. This suggests hotter and drier summers with less cloud cover. Similar trends can be seen for Tehran, however less pronounced in magnitude. Whilst the changes for coastal sites of the Arabian Peninsula are more evenly distributed over the year, the absolute temperature change is likely to have major implications for places like Kuwait, as for example the August mean temperature is predicted to rise from 38.3 °C at present to 43.0 °C by the end of the century. Averaged over the year Larnaca and Damascus show the least significant overall changes which indicates a mediating influence of the Mediterranean Sea. The wind speed remains largely unchanged at most sites. However, a slight decrease is seen for Cairo, Kuwait and Riyadh during the summer months whilst Ankara experiences a small increase.

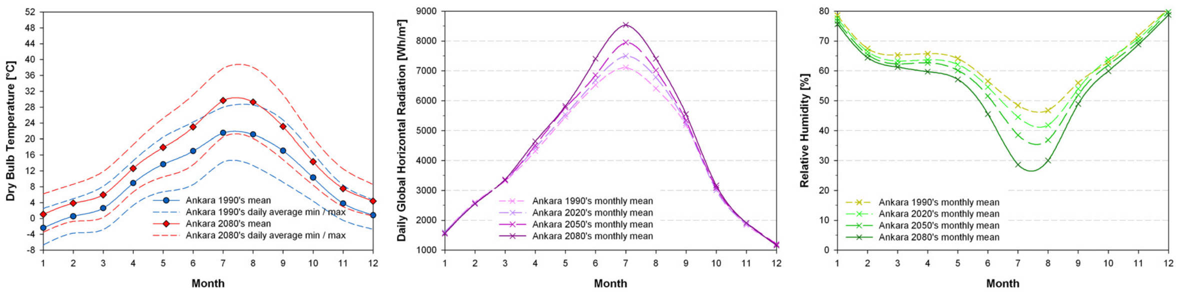

Figure 4 – Ankara Esenboga: (a) Average daily mean, minimum and maximum temperature for the 1990s and 2080s, (b) global horizontal radiation over time and (c) relative humidity over time

Figure 5 shows the long-term annual mean temperature trends for Tehran and Cairo in comparison to the EPW data. Whilst a close match between the 'present-day' EPW data and the corresponding observed data can be seen for both sites, there is a clear difference in the linear temperature trends. This may be related to different developments in urbanisation. However, since about 1980 population growth has been similar in both cities (Figure 5). Furthermore, current aerial views highlight similar levels of urbanisation at both weather stations. However, it is possible that Tehran airport and its weather station were more rural in the 1960s than Cairo airport which would explain a more upward temperature trend. This serves to highlight that EPW data is likely to include local microclimatic conditions of the weather site which will transfer to the 'morphed' weather series. Therefore, prior to planning a building and its services for a specific location, the representativeness of the EPW data for this location needs to be established. This will be difficult in practice and highlights the need for several weather files for conurbations in order to include/exclude effects such as urban heat islands.

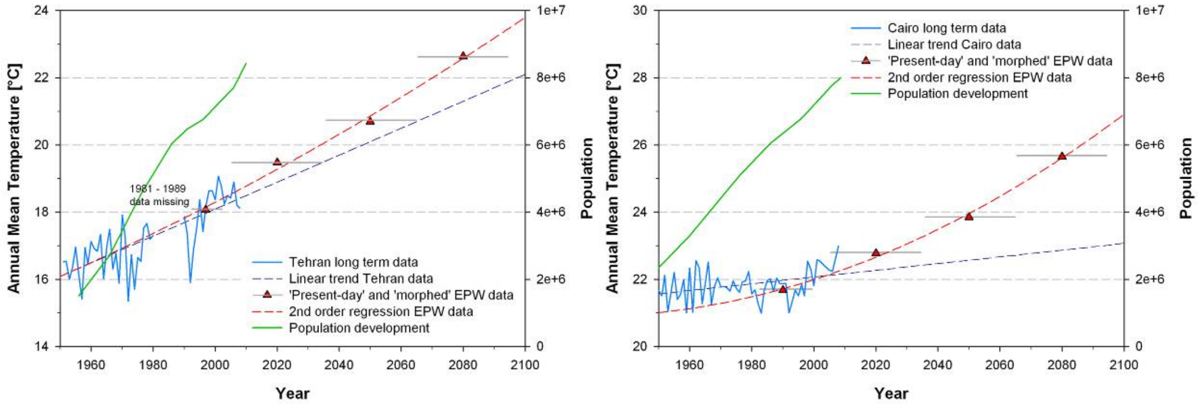

Figure 5 – Comparison of the long-term annual mean dry bulb temperature trends and the EPW data for the international airports of (a) Tehran and (b) Cairo, also including population development

3.2 Development of future cooling loads

The development of future cooling loads at the 8 given sites was investigated using the TRNSYS simulation engine. As underlying building model CIBSE TM33 Test G7.2 for assessing annual heating and cooling demands was used [20]. This model which is shown schematically in Figure 6 represents a simple simulation model with a heavyweight construction and high performance glazing. It is normally used for software accreditation with a defined set of weather data. However, in this study, rather than using a fixed ground temperature at 10 °C as in the TM33 test, the ground was assumed as a boundary of identical temperature. As can be seen in Figure 7, compared to a 1990s baseline the cooling load for the investigated weather stations is predicted to be typically about 35 to 55 % higher by the end of the 21st century. The only weather station that does not follow this pattern is Ankara where the changes are such that summer cooling which was previously comparably limited becomes essential, whilst all other sites have already got notable cooling loads at present.

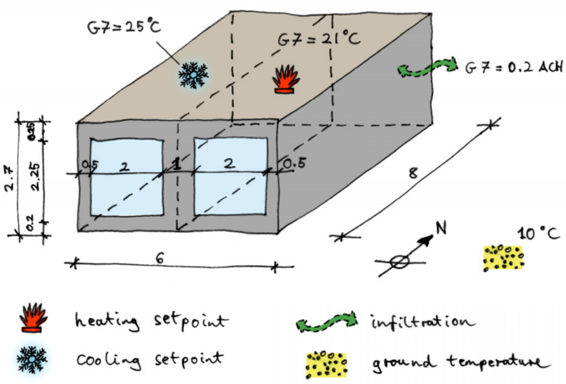

Figure 6 – CIBSE TM33 simulation model parameters [20]

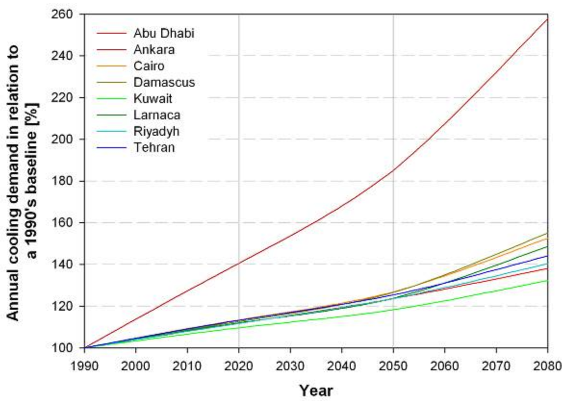

Figure 7 – Predicted change in annual cooling demand in relation to a 1990s baseline

4. Conclusions

It has been demonstrated that the 'morphing' approach is suited for generating climate change weather data for assessing the future performance of buildings and cities in the Middle East. Data generated for a medium-high emissions scenario highlights that by the end of the century cities on the Arabian Peninsula are likely to face summer mean temperatures frequently exceeding 40 °C. This will impose challenges for life in these cities. Furthermore, it has been shown that more inland locations are likely to be more affected than coastal areas. The potentially strongest shifts in climate experienced in the region were determined for Ankara and Tehran. The relative increase of air-conditioning loads was found to be greater for Mediterranean areas than for sites on the Arabian Peninsula, probably as a result of a reduced cloud cover coupled with a lower standing sun. This highlights the need for considering appropriate solar shading devices in subtropical climates whilst keeping the amount of glazed area at a sensible level. The case of Ankara further demonstrates that areas which currently only require limited building cooling are likely to depend on it in the future. In addition, the study highlights the need for more detailed 'present-day' weather data for the investigated cities as the localised climate potentially captured in the current files may not to be representative for a wider area.

5. Acknowledgements

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