Development of future weather data set based on SRES scenario

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Summary

Energy performance certificates, which are required in Norway from Jul2010 onwards, are likely to become important in determining a building's value and could potentially influence public perception of the 'greenness' of a building's occupant. Therefore, in view of the legal, societal and financial drivers for reducing energy consumption, performance assessment and prediction using appropriate tools such as energy performance simulation programs is becoming increasingly important. The aim of this study was to produce a future weather data file set that could be usable for a variety of simulation programs and is close to current industry standards. The baseline period to which the future weather data was related to represents the years 1961–1990, the current meteorological 'climate baseline' used for generation of the majority of building performance simulation weather files.

Future weather data consist of a set of climate change data for the 2020s, 2050s and 2080s. Here, the same 30 years periods were taken as basis. Results show that predicted future climate change will increase outdoor temperatures and solar radiation in Norway. The projected temperature rise over the next 100 years indicates a reduction in heating degree days and an increase in cooling degree days. This has the potential to reduce energy use in Norwegian buildings. However, thermal comfort during summer months is becoming more important when designing energy efficient buildings.

Focus should be put on applying appropriate strategies to passively cool buildings in Norway and to improve summer thermal comfort and address related overheating problems in future summer periods that might even extend it to autumn and spring seasons.

Keywords: Include list of keywords (maximum of ten keywords)

1. Introduction

It is evident that a changing climate and its implications will need to be reflected in future building design and refurbishment in form, material choice, thermal mass and building services [14]. However, in keeping with the tradition of the 20th century modern architecture movement, building design is still most commonly driven by aesthetic and functional considerations rather than environmental performance [20]. This ultimately can lead to a 'make it work' strategy when the building services are to be integrated into an environmentally unsound design approach. In addition, this also increases the risk of buildings failing to perform if the mechanical and electrical (M&E) design is not undertaken carefully from the onset of planning right through to the commissioning of the M&E plant [8]. Furthermore, this type of design approach adds to the running costs of a building as architectural failures are compensated by energy consuming mechanical equipment. Climate change can be expected to reinforce such cost implications and ultimately may render parts of the building stock economically unviable. Therefore, climate change assessment addressing the future performance of new building designs as well as existing buildings can be expected to become increasingly important within the next few years.

In Norway the need for appropriate climate change weather files for building performance assessment is reinforced by the fact that large proportions of the building stock, in particular office buildings under summer conditions, already often perform poorly during current periods of hot weather [17]. Based on the data provided by the Norwegian energy agency (enova), approximately 97% of Norwegian commercial floor space (offices and retail) is equipped with balanced mechanical ventilation system and 30% of that can be expected to have cooling facilities installed at present [9]. The majority of mechanically cooled floor space is likely to be installed in large buildings which might not be designed to make use of natural ventilation/cooling strategies. The New Norwegian technical requirements (TEK07) clearly state that mechanical cooling shall be avoided [21]. The potential for passive cooling strategies in Norwegian climate has been found to be large [2,11]. Determining the future performance of such office buildings under hot summer conditions is, therefore of key importance.

2. Objectives

The aim of this study was to produce a climate change weather file set that would be usable for a variety of simulation programs and is close to current industry standards. Therefore, a decision needed to be taken as to which simulation platforms would need to be supported and the weather file type that would be appropriate. In view of an analysis it was decided that the most sensible approach was to develop TMY2 files for climate change and to also provide EPW files which in essence represent a modification of the original TMY2 file type structure [11].

3. Generation of weather data files

In order to generate the TMY2/EPW climate change weather files as required for building simulation an appropriate methodology needed to be identified. Guan compared different methodologies [10]. The scope was to use and transform the results of existing climate change datasets so that they could be incorporated into these standard weather file types. Therefore, existing climate change weather datasets and methodologies for their generation were reviewed in their suitability in Jentsch et al. [12].

3.1 Global and regional climate change models

In its Fourth Assessment Reports the IPCC uses six basic global emissions scenarios which depend on different assumptions for future economic growth, resource consumption, technology implementation, social equity and global population development [18]. These scenarios, which do not include targeted strategies for climate change mitigation, essentially represent possible development pathways of human activities and function as a baseline for climate change modelling.

Several global climate models for simulating the effects of climate change have been developed and results integrated into the IPCC Assessment Reports. Those so-called atmosphere–ocean general circulation models previously had a coarse grid spacing of between 250 km and 500 km but the grid resolution has significantly improved for the Fourth Assessment Report [18].

3.2 Choice of scenario for global emissions model

The typical climate change scenarios are derived for different global carbon emission scenarios as reported by Nakicenovic et al. and detailed in Table2 [16].

Table 1 Four emission scenarios from Special Report on Emission Scenarios (SRES) [16,18]

IPCC Global carbon emissions			Temperature change (°C at 2090-2099 relative to 1980-1999) a, b	
SRES	Emission level	C emissions (GtC)	best estimate	likely range
B1	low	< 1100	1.8	1.1 – 2.9
B2	medium–low	1100- 1450	2.4	1.4 – 3.8
A2	medium–high	1450- 1800	3.4	2.0 – 5.4
A1F1 c	high	> 1800	4	2.4 – 6.4

a) These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity, and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs) as well as observational constraints.

b) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

c) A1C and A1G have been combined into one fossil-intensive group A1FI in the SPM

Table 2 Characteristics of SRES A2 [16]

Characteristic	level
Population growth	high
GDP growth	medium
Energy use	high
Land- use changes	medium/high
Resource availability	low
Pace of technological change	slow
Direction of technological change	regional

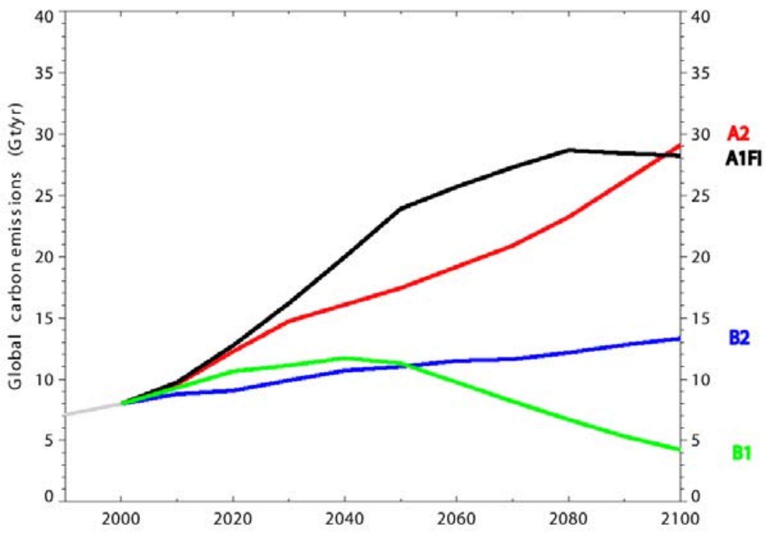

Fig. 1 Global emissions of different SRES scenarios [18]

The different scenarios have different future outlooks (storylines) in respect to the following parameter:

- Nature of the global and regional demographic developments in relation to other characteristics of the storyline.
- Extent to which economic globalization and increased social and cultural interactions continue over the 21st century.
- Rates of global and regional economic developments and trade patterns in relation to the other characteristics of the storyline.
- Rates and direction of global and regional technological change, especially in relation to the economic development prospects.
- Extent to which local and regional environmental concerns shape the direction of future development and environmental controls.
- Degree to which human and natural resources are mobilized globally and regionally to
- achieve multiple development objectives of each storyline.
- Balance of economic, social, technological, or environmental objectives in the choices made by consumers, governments, enterprises, and other stakeholders

With respect to the different emission scenarios outlined in SRES it was decided to choose scenario A2 for future weather data generation. The SRES A2 scenario is characterized in Table 2 and related global emissions are illustrated in Figure 1.

It can be seen from Table 2 that SRES A2 is characterized by high population growth with a medium GDP growth, high energy use and medium/high land-use changes, low resource availability, and slow technological change pace with regional direction [16].

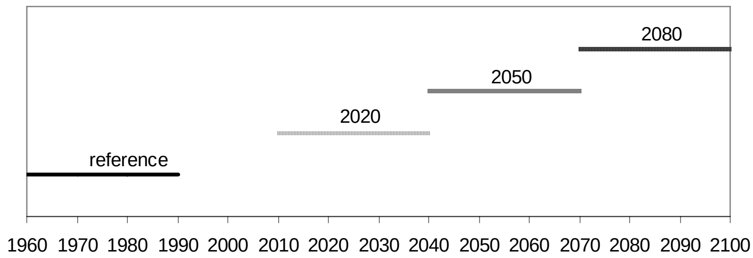

Fig. 2 Global emissions of different SRES scenarios [18]

The baseline period to which the climate change data should relate to its simulated timeframe representing the years 1961–1990. This timeframe also represents the current meteorological 'climate baseline' used for generation of the majority of building performance simulation weather files [1,15].

Future weather data consist of a set of climate change data for the 2020s, 2050s and 2080s. Here, the same 30 years periods were taken as basis as shown in Figure 2. This results in a data set Oslo 2020 which relates to the period between 2010 and 2039, a data set Oslo 2050 which relates to the period between 2040 and 2069, and a data set Oslo 2080 which relates to the period between 2070 and 2099.

3.3 Morphing of present-day weather data

Based on the SRES data output Belcher et al. have developed a methodology for transforming TRY and DSY weather files into climate change weather years [4]. Hourly EPW weather data for the present-day climate is adjusted with the monthly climate change prediction values of the HadCM3 scenario datasets. This methodology is termed 'morphing' due to the fact that data of existing weather sites is 'morphed' into climate change weather data. The basic underlying methodology for weather file 'morphing' consists of three different algorithms depending on the parameter to be changed:

(1) a 'shift' of a current hourly weather data parameter by adding the HadCM3 predicted absolute monthly mean change [4]:

$$x = x_0 + \Delta x_m \tag{1}$$

where
x is the future climate variable,
x_0 the original presentday variable and
Δx_m the absolute monthly change according to HadCM3.

This method is, for example, used for adjusting atmospheric pressure.

(2) a 'stretch' of a current hourly weather data parameter by scaling it with the HadCM3 predicted relative monthly mean change [4]]:

$$x = a_m * x_0 \tag{2}$$

where
a_m is the fractional monthly change according to HadCM3.

This method is, for example, applied for 'morphing' the present-day wind speed.

(3) a combination of a 'shift' and a 'stretch' for current hourly weather data. In this method a current hourly weather data parameter is 'shifted' by adding the HadCM3 predicted absolute monthly mean change and 'stretched' by the monthly diurnal variation of this parameter [4]:

$$x = x_0 + \Delta x_m + a_m(x_0 - (x_0)_m) \tag{3}$$

where

$(x_0)_m$ is the monthly mean related to the variable x_0, and
a_m is the ratio of the monthly variances of Δx_m and x_0.

This method is applied for adjusting the present-day dry bulb temperature. It uses the HadCM3 predictions for the monthly change of the diurnal mean, minimum and maximum dry bulb temperatures in order to integrate predicted variations of the diurnal cycle.

Detailed information on the application of these ‘morphing’ equations on various TRY/DSY weather data from the U.K. is given in the appendix of the paper by Belcher et al. [4]. In essence, a future weather pattern is produced that is largely analogous to the present-day weather in terms of diurnal cycles and extremes. On the other hand, the advantage of this approach is that spatial downscaling of the climate change data is achieved due to baseline weather data from a physical location [4]. Furthermore, the generated data is ‘‘likely to be meteorologically consistent’’ [4].

3.4 Generation of climate change TMY2/EPW files

A range of parameters that are required for a TMY2/EPW file are not provided by the original TRY/DSY data. For example, daylight, humidity and precipitation parameters are missing completely. Nevertheless, with the exception of precipitation all relevant missing parameters can be calculated from other parameters available in the TRY/DSY data. Table 2, which structurally follows the EPW file data convention [7], gives an overview of all the parameters contained in a TMY2/EPW file.

Climate change TMY2 and EPW files were produced in a step by step procedure following the file conventions outlined in the manuals by Marion and Urban (1995) for TMY2 files and Crawley et al. (1999) for EPW files[7,15]. The EPW file header consists of eight lines containing basic information on location, design conditions, etc. whilst the TMY2 file header comprises of only one line detailing the location. Most of the EPW header parameters are not required by standard building simulation programs. Therefore, in accordance with weather files generated by commercial packages such as Meteonorm only a limited number of header parameters were addressed (Meteonorm). Apart from integrating location parameters, such as longitude, latitude and altitude, the monthly average ground temperature at 1 m depth was calculated using the temperature correlation equation developed by Kusuda and Achenbach [13].

For calculation of humidity parameters psychrometric formulae detailed in the ASHRAE Handbook— Fundamentals (2005) were utilised, whilst solar geometry equations required for calculating some of the radiation parameters were taken from CIBSE Guide J [3,5]. Downwelling longwave radiation which is required for EPW files was derived from an equation suitable for all sky conditions which was developed by Crawford and Duchon [6]. This equation is based on the values for dry bulb temperature, vapour pressure and cloud cover. All daylight components required for the files were generated from the available radiation parameters in the CIBSE data according to the method described by Perez et al. (1990) which is based on experimental observations made in the United States and Europe [19].

4. Results

The results of the parameter changes are given in Table 3. It can be seen that average, minimum and maximum temperatures (TMAX, TMIN) increase for all scenarios. Also solar radiation and precipitation increase for all scenarios whereas pressure, relative humidity, and TCLW as well as wind reduce. Monthly temperature averages are illustrated in Figure 3 and overlaid in a psychrometric chart.

Table 3 Morphing results for Oslo weather data file

parameter	unit	2020	2050	2080
Temperature	(°C)	1.15	2.44	4.10
TMAX	(°C)	1.11	2.43	3.96
TMIN	(°C)	1.22	2.70	4.38
DSWF	W/m²	1.51	1.60	0.97
TCLW	% points	-0.47	-0.50	-0.24
PREC	%	4.35	7.72	13.85
RHUM	% points	-0.62	-1.08	-1.54
MSLP	hpa	-0.01	-0.23	-1.22
WIND	%	0.60	-0.86	-1.24

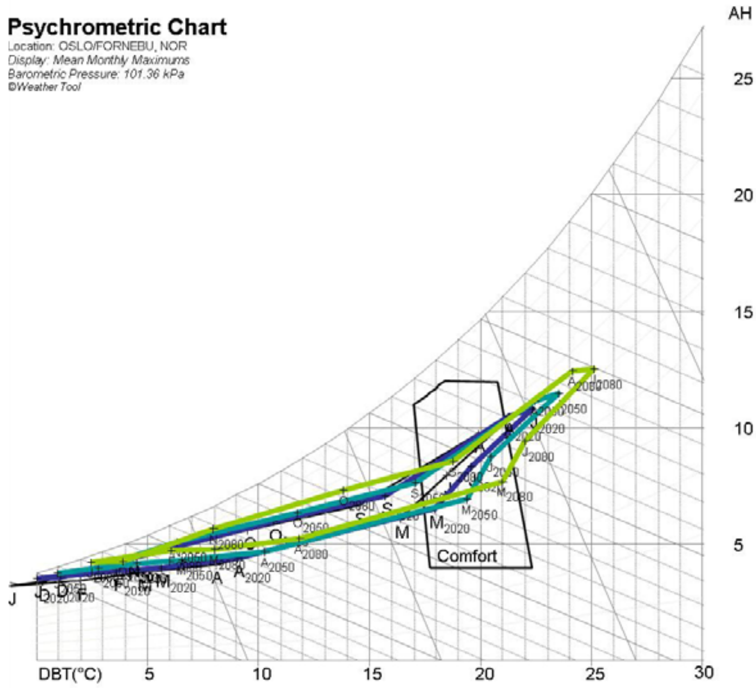

Fig. 3 Morphing results for Oslo weather data file

Table 3 Morphing results for Oslo weather data file

location	Latitude	HDD	CDD
Bergen	60.2	3878	17
Oslo	59.9	4085	27
Trondheim	63.4	4379	18
Gardemoen	60.0	5085	13
Tromso	69.4	5339	0
Karasjok	69.2	7346	5
Oslo-2020	59.9	3725	49
Oslo-2050	59.9	3325	79
Oslo-2080	59.9	2844	146

Figure 3 illustrates the predicted shift in future weather files by showing monthly temperature averages for Oslo for the periods 2020, 2050, and 2080 as mentioned above. It can be seen that morphing the existing measured weather data from the period 1961 until 1990 results in a temperature shift towards a warmer and slightly less humid climate.

Average temperatures in the cooler months (J, F, M, A, S, O, N, D) shift towards warmer average temperatures.

Average temperatures in spring and autumn are predicted to become warmer and move into the comfort zone and beyond. For example is for the month May an average temperature shift from 11.3 (measured) to 13.1 (2020), 14.5 (2050), and 16.0 (2080) respectively predicted. It can be seen that average temperatures in May 2020 lay within the usual comfort zone and even 2080 May outdoor temperatures lay within the comfort zone. But average temperatures in June move in 2080 out of the comfort band illustrating the need to apply appropriate passive cooling strategies.

5. Conclusions

5.1 Future weather data

Using 30 year time-slices is consistent with standard meteorological practice for defining a region's *climate*. The time-slices are therefore produced by taking the mean climate for periods conventionally defined (baseline 1961–1990) as the

- 2020s (2011–2040),
- 2050s (2041–2070) and
- 2080s (2071–2100).

Based on the A2 output of the 4AR (IPCC) hourly weather data for the present-day climate was adjusted with the monthly climate change prediction values of the scenario datasets. This methodology is termed 'morphing' due to the fact that data of existing weather sites was 'morphed' into climate change weather data. EPW weather data files were derived from observations. This makes the 'morphing' approach particularly attractive for climate change weather file generation as the resulting files can be directly related to the standard weather data used for building compliance testing. Furthermore, the basic EPW data is already available for use in advanced building simulation programs. It needs to be noted however, that the approach of 'morphing' present-day weather data with monthly climate change predictions misses details of potential future changes in diurnal weather patterns or the extent of future extreme weather events such as heat waves [12].

5.2 Climate change

SRES A2 scenario that was chosen in the weather data development embeds a large amount of uncertainties, especially with regard to:

- Rates and direction of global and regional technological change, especially in relation to the economic development prospects.
- Extent to which local and regional environmental concerns shape the direction of future development and environmental controls.
- Degree to which human and natural resources are mobilized globally and regionally to achieve multiple development objectives of each storyline.
- Balance of economic, social, technological, or environmental objectives in the choices made by consumers, governments, enterprises, and other stakeholders

5.3 Design consequences

Results show that predicted future climate change will increase outdoor temperatures and solar radiation in Norway. The projected temperature rise over the next 100 years indicates a reduction in heating degree days and an increase in cooling degree days. This has the potential to reduce energy use in Norwegian buildings. However, thermal comfort during summer months is becoming more important when designing energy efficient buildings. Focus should be put on applying appropriate strategies to passively cool buildings in Norway and to improve summer thermal comfort and address related overheating problems in future summer periods that might even extend it to autumn and spring seasons.

It means a shift in the design paradigm away from focusing on reducing heat losses towards focusing on the integration of passive cooling strategies.

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