

WHAT GUIDANCE WILL BUILDING MODELLERS REQUIRE FOR INTEGRATING FUTURE CLIMATES INTO BUILDING PERFORMANCE SIMULATION?

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ABSTRACT

We need to simulate building proposals in future weather conditions because the climate is changing. This increases the complexity of decision-making for the designers and building modeller. For instance, the latest climate projections for the UK (UKCP09 from UK Climate Projections, 2009) are probabilistic having large numbers of associated weather files. This paper reviews approaches to using future weather data including running multiple simulations and post-processing, narrowing the choice of files using a framework for selection, and using building unique functions. The paper finds that a framework may be beneficial and suggests the investigation of climate data prior to simulation.

INTRODUCTION

Problem definition and project objectives

In order to assess the performance of building design proposals under future weather conditions, future weather files are utilised in simulation programs. In considering driving forces for the take-up of future weather data, note that there is currently no known regulation in the UK that requires its use. One driver for the use of such data is research council and other government funded activities. The Technology Strategy Board's "Design for Future Climate: Adapting buildings" competition (see *Competitions* webpage, Technology Strategy Board, 2012) has allowed a limited number of practitioners with resources to explore the possibilities and issued involved. Other drivers might be client concerns regarding health issues related to overheating, insurance claims on poorly designed buildings, and reputational concerns for building owners.

Future weather datasets include the UKCP09 based, and soon to be released CIBSE Future Weather Years, and the PROMETHEUS weather files, (available from *PROMETHEUS* website, University of Exeter, 2012) (Eames, 2011) both of which include different time-periods, emissions scenarios and probability levels. The Chartered Institution of Building Services Engineers (CIBSE) commissioned the revision of the CIBSE Future Weather Files,

using the morphing method (Belcher et al, 2005), to reflect the UKCP09 projected climatic averages. PROMETHEUS is an EPSRC funded project based at the University of Exeter, which has produced future weather files based on the UKCP09 Weather Generator. In the case of CIBSE weather files for each of the 14 UK locations available, there will be potentially 27 files (see Figure 1). For weather file generation general methodologies refer to *Guide J: Weather, Solar and Illuminance Data* (CIBSE, 2002) and for future morphing methodologies refer to *TM48 Use of climate change scenarios for building simulation: the CIBSE future weather years* (Hacker, Capon, Mylona, 2009). With this increasing number of files in datasets of future weather data from either CIBSE or other sources, some thought as to their appropriate use is required. CIBSE in collaboration with UK Climate Impacts Programme (UKCIP) have undertaken a two year Knowledge Transfer Partnership (KTP) to aid weather data selection for analysing building design proposals. This paper in comparing approaches to use of future weather data includes an approach developed by this project.

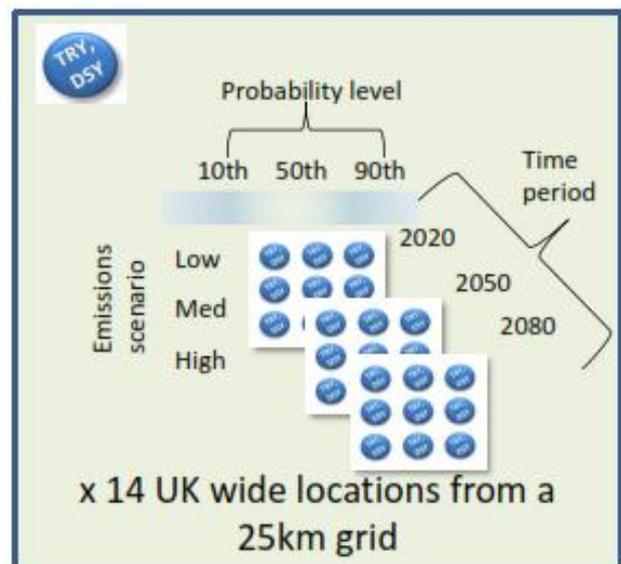


Figure 1: CIBSE future weather files

A more in depth explanation of this approach can be found in *Understanding future climate data from UKCP09 for weather data selection: a methodology*

by Shamash, Mylona & Metcalf (2012) from Proceedings of the CIBSE ASHRAE Technical Symposium 2012.

UKCP09 and the introduction of probability

The latest UK climate projections provide information until the end of this century in overlapping periods of 30 years, see Figure 2.

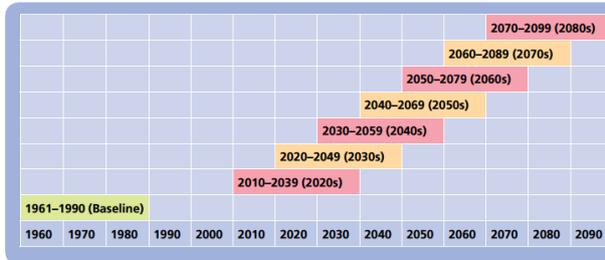


Figure 2: Time-periods in the UKCP09 climate projections

The emissions scenarios used in UKCP09 are derived from three International Panel on Climate Change (Pachauri, R.K. and Reisinger, A, 2007) emissions scenarios, called A1F1, A1B and B1, see Figure 3.

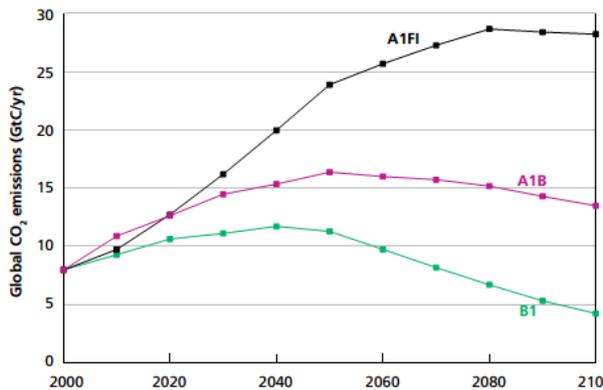


Figure 3: Emissions scenarios in the UKCP09 climate projections

UKCP09 are the first climate projections to be probabilistic in nature. This means that when looking at a cumulative distribution function (CDF) such as the diagram in Figure 4 from the UK Climate Projections (2010), the vertical value of the climate variable is the probability of such change up to this value happening. For instance if the horizontal axis is change in annual mean air temperature, from the graph, there is 22% probability of temperature change being less than 3°C, or there is 78% probability of being greater than 3°C.

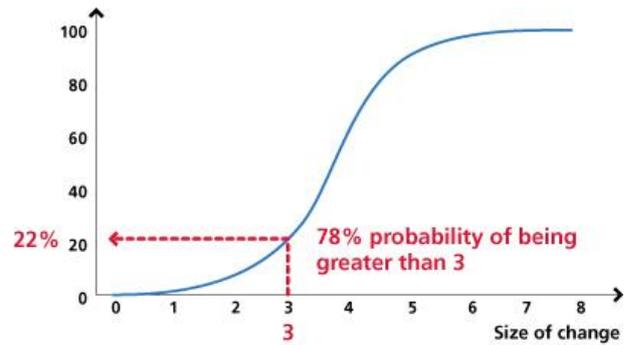


Figure 4: Diagram of a cumulative distribution function (CDF) representation of probabilities available in the UKCP09 climate projections (2010)

Aims of the paper

This paper aims to assess the approaches to the use of future weather datasets to analyse the performance of buildings in the future. In particular, it is concerned with datasets that have a large number of files representing future weather variants of emissions scenarios time periods and probability levels, such as those derived from UKCP09 probabilistic climate projections.

Possible developments in building performance simulation affecting the use of future weather data

Simulation tools are currently used by the industry to develop design solutions and comply with building regulations. All simulations require effective reporting of the results to assess against design criteria. A comprehensive review of building simulation software (Crawley et al, 2005) makes the point that although building simulation tools are among the largest of any software applications, the vendors have not created database formats for the outputs, rather assuming use of third party spreadsheet. With the advent of Building Information Modelling (BIM) there is a possibility in the future of a bi-directional interface between building design software, such as BIM models and building performance simulation software, as discussed by Toth et al (2011), at Building Simulation 2011. The authors also suggest that iterations might be introduced into building performance simulation in a similar way as to how it is used in the aerospace industry.

The format of the paper

A literature review will look at existing guidance on the use of future weather data, and compare various approaches. The paper includes in the comparison a Decision Making Framework developed by a KTP project carried out by the author.

LITERATURE REVIEW

The following publications provide guidance on the use of future weather data.

TM48 Use of climate change scenarios for building simulation: the CIBSE future weather years (Hacker, Capon, Mylona, 2009) provides background reading to explain the purpose of, science behind, and method of construction of the CIBSE Future Weather Files. Regarding the question of how the future weather files should be used it states “*At present there is no accepted methodology for carrying out climate change risk assessments for the environmental design of buildings and it is envisaged that methodologies will evolve as greater use is made of climate change projections in design*”.

Published this year, *Designing Zero Carbon Buildings Using Dynamic Simulation* (Jankovic, L) 2012) does not contain a methodology for using future weather data. It provides instead an example exercise that uses both future climate and weather data. In terms of future climate data, this has been utilised to gain an initial overview of the climate prior to carrying out simulations. This involves exploring raw data available from the UKCP09 climate projections website. It states:

“in order to assess what the future climate of Birmingham might be, we will investigate average temperature increase on a monthly and on an annual basis, as well as the increase in the warmest day coldest night temperatures. We will also investigate changes in relative humidity, cloud cover, and incident solar radiation on the horizontal surface. In order to reduce the number of variables in the analysis we will focus on a medium emissions scenario, assuming 50th percentile or a median estimate of future weather predictions”. Jankovic shows that climate averages may have a place in the initial studies and he encourages the consideration of future climates in building, design by showing practical examples. However, the inclusion of medium emissions scenario with no explanation of the reasons for such inclusion means that the process of choosing future weather files could not be classified as a methodology or decision framework.

De Wilde has considered the question of methods of using future climate and weather data in a number of papers. For instance *Towards probabilistic performance metrics for climate change impact studies*. (De Wilde, P, Tian, W, 2011) comments on the lack of simulation studies that have used probabilistic data considering that “climate projections have an inherent uncertainty”. Similarly Mylona writing in a special issue of Building Services Engineering Research & Technology (BSERT) in 2012 welcomes the use of probabilities, stating “[the] better representation of uncertainty in the [UKCP09] projections encourages the incorporation of future risks by those planning to adapt to a changing climate”.

CRITERIA FOR ASSESSING THE APPROACHES

Building performance simulation needs to be effective, appropriate, within the capability and resources of the design team (whether they be building services engineers, architects, sustainability consultants or others) and to be undertaken to quality assurance (QA) standards.

Applications Manual AM11: Building Energy and Environmental Modelling (Hand et al, 1998) (currently under revision) includes a chapter on establishing a simulation capability, and states that the four main concerns for effective simulation are 1) human resources 2) computing environment 3) training and 4) quality assurance. Regarding QA it states that its purpose should be to:

- *instil confidence in clients that the work is under-taken to a consistently high standard*
- *ensure that the simulation work is addressing the needs of the client*

All approaches for incorporating future weather files, presented here, are in their infancy, and some speculation shall be made about the future of these approaches. The criteria for assessing those approaches are:

- Availability of resources required
- Technical skills, ease of use & length of process
- QA for consistency and accountability to clients needs
- Future prospects for the approach
- Advantages and disadvantages

REVIEW OF APPROACHES

a) Multiple simulations (for instance by batch or parametrically) with extensive post processing

What is the approach?

The approach includes the simulation of each and every file of the future weather dataset. It might be through preparing the model and then activating a batch of simulations that individually use each future weather file. Or it might be through simultaneous parametric simulation. This approach, because of the non-discrimination of future weather inputs, inevitably requires careful studying of the output data, called post processing. It might be the case that risk assessments of the performance of the buildings under future conditions form part of the post processing, as detailed in an example below.

Examples of its use and development

One example of the use of multiple simulations with extensive post-processing is AECOM’s work on the London School of Tropical Medicine and Hygiene, reported in an Adaptation Strategy (Elder, K, 2011). The project won funding through the Technology

Strategy Board (TSB)'s *Design for Future Climate: Adapting Buildings* competition to consider adaptation to climate change within the design process. Here multiple PROMETHEUS files were used (available from University of Exeter website, see references for URL). A matrix with an axis of 'Likelihood' and "Consequence" was used. For all risks assessed for the building, consequence was in the range from

'Catastrophic/5: Permanent loss of building use; major risk to occupant health/safety and possible loss of life' to 'Insignificant/1: Building will continue to function without action, occasional discomfort to occupants but no risk to health/safety'.

In the case of overheating assessment the consequence ranged from:

'Almost certain for current climate - 10th percentile' to 'Very unlikely for the 2080 - 90th percentile'.

Another approach (Tian, de Wilde, 2011) including a risk assessment in the post processing, takes the Probabilistic Risk Assessment (PRA) from Modarres (2006).

Availability of resources required

Carrying out multiple simulations parametrically or otherwise is increasing in popularity. At the time of writing batch processing is possible with at least one of the leading software tools, and parametric simulation with Energy Plus via plug-ins. Computing power is an issue. The super computers that may be available for research within this area, are usually out of reach of engineers or architects. However, there are cost implications due to the modellers time in simulating a larger set of future weather conditions.

Technical skills, ease of use & length of process

Modellers may be used to working with complex level of input and output, but it would require an experienced modeller to undertake this approach. Logistically, to run batch or parametric simulations and process the results requires a person to be methodical. The consideration of the outputs of the simulation will need to be assessed based on a risk assessment which requires the understanding of the wider implications of the use of each of the variables, such as the choice of emissions scenario. The process of simulation may take several hours or days.

QA for consistency and accountability to clients needs

It is possible with this approach, to implement QA procedures on the use of input data and other design variants that might extent to file naming. It would be beneficial for the post processing to have reasons for inclusion or exclusion of results derived from particular weather data files. This would ensure that full consideration of clients' needs, and retained knowledge of the decisions regarding the use of future weather data. An example is that if probability

levels from 50th, 67th and 90th percentiles are used for an overheating assessment, but at some point 90th are excluded, a reason and record should be available to the client, so the ramifications can be explored. There are no known QA processes for dealing with parametric simulation.

Future prospects for the approach

Even after post processing of the results it is possible that multiple variants of future weather files are retained for client discussions. The development of this approach might be to formalise the use of risk assessments as part of post processing.

Advantages and disadvantages

The benefit of this approach is the increase in knowledge of the performance of the building under multiple climates. By not limiting the input weather data any combination of the variables can be called upon and the results scrutinised. Furthermore, comparisons can be made between different future weather conditions. This, combined with the possibility of using different design variants, makes it a powerful data rich approach. The disadvantage is that in the wrong context, the input weather data will not make any discrimination to filter out inappropriate variants, and processes may not be in place to make clear the meaning of these inputs when the simulation results are assessed.

b) Narrowing down the selection of future weather files with a decision-making methodology

This approach differs from multiple simulations as its practice may reduce the number of future weather files used. In this paper a methodology is suggested developed by the authors, that considers a summary of the future climates for a variety of time periods, emission scenarios and probability levels, and specific building project objectives.

The 'Decision Making Framework for selection of future weather data' and 'ProCliPs'.

The Framework (see Figure 5) is a suggested methodology for planned and systematic use of future weather data. Probabilistic Climate Profile (ProCliP) graphs are used in the Framework as well as being a resource for better understanding of the changing climate. Both were developed within a Knowledge Transfer Partnership between UKCIP and CIBSE. The Framework can be used by designers for new or existing buildings. The first step is the choice of location. The second step requires from the user to state their design aims, and consolidate performance analysis requirements. At step 3 a ProCliP is chosen for the relevant climate variable and the particular site from a range of 14 locations across the UK that will be available from this project. Probabilistic Climate Profiles (or ProCliPs) are graphs developed to aid the exploration of climate averages on a site-by-site basis, see Figure 6. Climate projections are available on maps, or as

cumulative frequency distributions available in the UKCP09 User Interface (UK Climate Projections User Interface, 2012).

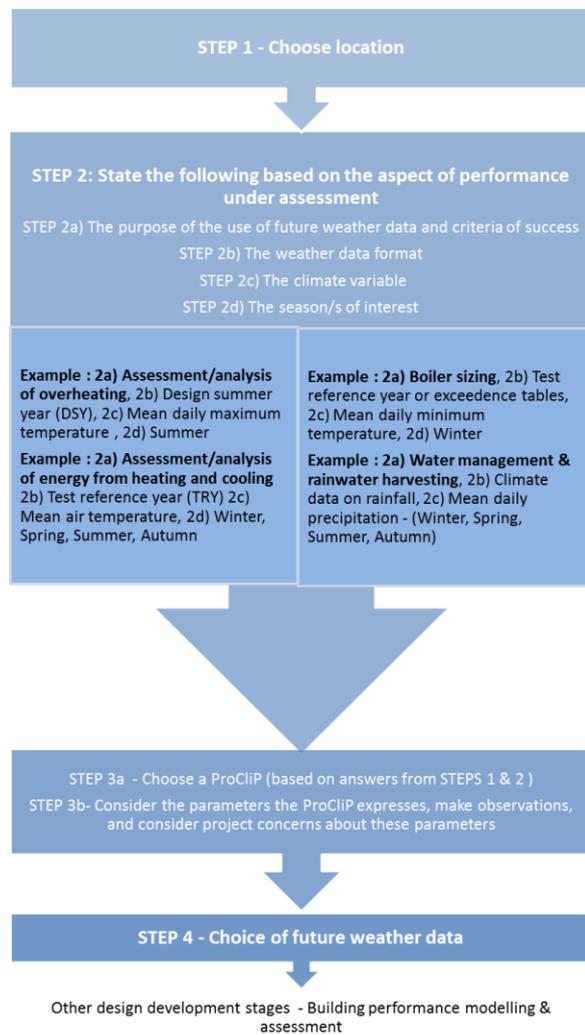


Figure 5: Decision Making Framework for selection of future weather data

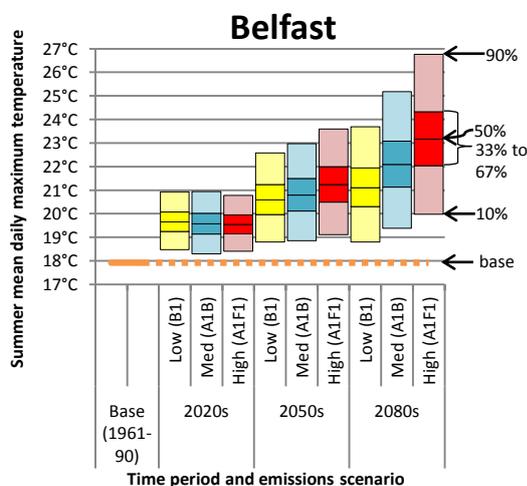


Figure 6: Probabilistic climate profile for Belfast Mean daily maximum temperature

Step 3b, considers the parameters that the ProCliP expresses, i.e. the time-periods, emission scenarios and probability levels. Additionally, other questions are posed to the modeller that address the technical and other project considerations on the project. These consist of a) time period:

- the timespan and use of the building
- other considerations such as attitudes or case specific concerns

b) emissions scenario:

- the likely trend for future emissions
- other considerations such as attitudes or case specific concerns, and

c) probability level:

- technical considerations related to risk
- other considerations such as attitudes or case specific concerns

The consideration of these questions helps the user to narrow down the choice of possible weather data.

Availability of resources required

Choosing future weather files based on ProCliPs may require additional computing power as explained earlier. This approach is intended to have a lower impact on computing resources by narrowing the number of input files required. Since it is also possible that after consideration of the input files a large number is retained, there is a possibility that the computing power is similar to approach a). The future weather files are available as with approach a) with a financial benefit of reduced simulation times, saving modeller's time. There is no saving in weather file purchase cost as these are either freely available or charged by location.

Technical skills, ease of use & length of process

An understanding of the probabilistic future weather data is required in all approaches. In this approach it is the responsibility of the modeller to decide/communicate the questions posed in the Framework to the design team and client in order to narrow the choice of weather files. The simulation skills are similar to other approaches, but with lower data manipulation and coordination, the practitioners can concentrate on the analysis of a smaller number of outputs. The number of simulations could be reduced, but it is noted that it will still be greater than simulating building solely with current weather files.

QA for consistency and accountability to clients needs

The Framework could form part of the existing QA procedures for building performance simulation or perhaps encourage the formulation of procedures if there are none. This could include collectively deciding to use one particular emissions scenario throughout the project. This would mean that within

the design team, the different disciplines that use performance simulation, such as the lighting designers and the thermal comfort specialists, might decide collectively on the use of a single emission scenarios using the Framework. This would allow the clear communication of results to the client.

Future prospects for the approach

The approach could be further developed to include a checklist of weather datasets to be included or excluded. It could also include standardised reporting method for reporting to design teams and clients. There is also the potential for the approach to support a regulatory framework .

Advantages and disadvantages

The advantage of this approach is that the decisions are carried out in a planned and logical way. There is a low skill level required, and no additional requirements on simulation software resources. There is also a potential reduction in the length of simulation time.

c) Other approaches such as building specific functions and metamodels

These approaches are noted, however a full review against the criteria is not provided here.

The approaches discussed here are different in that they do not use pre-developed future weather datasets but data from a larger set of files, originally derived from UKCP09, through the use of stochastic weather generators. These are then statistically analysed to produce shortcuts to reduce the number of individual simulation runs.

The resultant tools may also be associated with building specific coefficients as developed by Coley and Kershaw (Coley, D, Kershaw, T, 2010) fingerprints such as developed by Williams, Elghali (2011) or 'Metamodels'. All these products can have similar relationships to the thermal aspects of a full building model but require less computational time to simulate. The Low Carbon Futures project created an overheating risk tool (Patidar S, 2011), that "runs a representation of the full suite of UKCP09 climate information for a specific climate scenario". It is currently successfully validated against results obtained from building simulation. The project modelled a variety of building types and a resultant tool can be used for any type of building. The Adaptation and Resilience Coordination Network website (UKCIP, 2012) carry updates on projects such as Low Carbon Futures. Whilst the authors of this paper have not investigated using the tools themselves, a brief discussion of the implications of the use of this or similar tools is made.

Advantages and disadvantages

The availability of such tools could mean that practitioners would not be required to carry out multiple simulations themselves. If such tools are

made widely available they would be likely to require low level of resources. There are also advantages in the reduction in simulation times.

DISCUSSION AND RESULT ANALYSIS

Various approaches for the use of large datasets for the assessment of buildings under future climates are reviewed in this paper are summarised in Table 1. The review highlights that the computation power and/or time might differ between approaches, with a) multiple simulations requiring extensive post-processing are likely to require greater IT resource than approach b) which is narrowing down the selection of future weather files using a decision-making framework.

Whilst the range or scope of the variety of future climates is likely to be broader in the former approach, it will endow a requirement of discrimination on 'useful' results and clear representations of the input and outputs.

The technical skills required are likely to be more extensive when dealing with the large inputs and outputs in the former approach, however whichever approach used would require good use of QA and reporting of decision making process and results. On the subject of QA it is likely that the approaches have not yet reached maturity, however a decision making framework as detailed here (approach b) may be a starting point. The absence of a reporting methodology of results, as highlighted by Crawley et al, earlier, might be an impediment for the widespread and effective use of the parametric approach of multiple climates. On the other hand the approach of narrowing down the climate selection would also benefit the better organisation and comparison of results.

In terms of future developments, it is likely that in general, in building performance simulation, parametric analysis will develop because of their capability to multi-variant designs to be used. The approach that seeks to narrow down the selection of future weather files by the use of a decision-making framework might be further developed to include a checklist for users, and standardised report to project participants.

Table 1: Comparison of approaches

	a) Multiple simulations (for instance by batch or parametrically) with extensive post processing	b) Reducing files by means of a methodology (the Decision Making Framework)	Other approaches such as building specific functions or metamodels
What is the approach?	Extensive simulation of all available future weather files	Simulation of only the future weather files that are deemed appropriate for the project	Simplification of models or use of functions, coefficients to represent the building.
Availability of resources required	<ul style="list-style-type: none"> • Use of highly powerful or time consuming computing capability • Though limited availability of computing capability, likely to become more widely available to modellers 	<ul style="list-style-type: none"> • Standard/possibly high computing capability. 	<ul style="list-style-type: none"> • Uses different input data as input files – stochastically generated data • Has potential to reduce simulation times
Technical skills, ease of use & length of process	<ul style="list-style-type: none"> • High level of simulation skills • High level of QA standards 	<ul style="list-style-type: none"> • Moderate, no additional technical skills for an average modeller, but high level of QA standards and judgement requirements in relation to risk attitude of the design team/client • The length of process depends on number of files retained after using the Framework 	
QA for consistency and accountability to clients' needs	No known QA procedures	Process is structured to allow for reporting	
Future prospects for the approach	Parametric approaches likely to develop in general in building performance simulation because of multi-variant design	Possible inclusion of checklists, reporting to clients	

CONCLUSIONS

The study has looked at various approaches in integrating probabilistic future weather files into building performance simulation practice. Two approaches to using the UKCP09 derived future weather files, vary from retaining the full range of the future weather files, to narrowing them down through a selection process, while a third uses building specific descriptions to enable the use of the full range of probabilistic weather files.

All approaches may have benefits and limitations. For design practices where a limited resource for simulation is available, it might be worth using a methodology for the selection of weather files to narrow down the selection to the ones relevant to the design task. This would also mean that important decisions about use of emissions scenario, time-period and probability are not left to the post processing stage, when their meaning might be less clear. On the other hand, for design practices that could benefit from fully exploiting the range of future climate information available, a detailed risk

assessment is recommended to be carried out in post-processing.

This paper can be seen as an introduction to the discussion around approaches to use of probabilistic datasets of future weather files. It has not covered the approaches in depth, or given quantitative measures of the impacts of approaches on delivery of projects, which might be topics of further research as the approaches mature.

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