DECISION SUPPORT FOR BUILDING ADAPTATION IN A LOW-CARBON CLIMATE CHANGE FUTURE:

The “Low Carbon Futures” project
The Low Carbon Futures (LCF) project has combined detailed building simulation and future climate projections to provide a series of outputs, including an overheating risk tool, for assessing the future performance of buildings in the UK. The LCF tool incorporates the 2009 UK Climate Projections, and generates multi-climate building performance estimations from just a single simulation output (as might be produced by conventional building software, such as IES-VE or TAS). The result, for given climate scenarios, is a spectrum of probabilities suggesting how that specific building might perform in the future, thus helping the user choose adaptation technologies that might reduce the risk of overheating or cooling failure.

To translate both the LCF tool and the background of the work appropriately to building practitioners, a series of focus groups, interviews and questionnaires were carried out with professionals working in London and Edinburgh. This enabled the tool to be tailored to a suitable audience, and also aided the project in understanding exactly how practitioners, at the design stage, approach the problem of thermal comfort in both domestic and non-domestic sectors.

The project found a wide variation in the importance attached to overheating across domestic and non-domestic sectors, as well as between the north and the south of the UK. For example, overheating analyses in the Scottish domestic sector, perhaps unsurprisingly, were not seen as a priority area. Conversely, practitioners based in the London area did note this as a concern in both current and future climates. The response of those from the non-domestic sector was more diverse. In Scotland, some participants did not feel overheating (or under-cooling) was a major concern despite evidence (of offices and schools struggling to maintain summertime comfort) to the contrary. However, across the UK for this sector in particular, the need to quantify and assess overheating risk was understood, with concerns expressed for the incorporation of new UKCP’09 probabilistic projections into this process.

The LCF tool itself is now at a stage where it can be applied to the simulation results of any building. Plans are also being formulated to extend the model for more widespread applications.

**Key messages**
- The LCF tool emulates the effect of climate on building simulation and allows building design teams to appraise alternatives using the latest climate projections
- Overheating and excessive cooling energy use can be modelled efficiently and risk assessments provided based on multiple climate scenarios
- Specific adaptation measures have been applied to case study buildings to demonstrate the use of the LCF tool
- When developing a design tool for adaptation, the needs and current practices of industry have to be understood for such a tool to succeed. However, it is equally important to encourage a change in practice if the current approach to building design does not allow provisions for future climate

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1. Introduction

The Low Carbon Futures (LCF) project\(^1\), carried out by the Urban Energy Research Group (UERG) at Heriot-Watt University, was a 3-year project investigating the use of the 2009 UK Climate Projections (UKCP’09) within building performance simulation and design. It was funded by the Engineering and Physical Sciences Research Council (EPSRC) as part of the Adaptation and Resilience to a Changing Climate (ARCC) programme. Taking case studies from both domestic and non-domestic sectors, a methodology was constructed that could identify the risks of such buildings “failing” in a future climate, either due to excessive overheating or the existing cooling systems becoming inadequate.

The premise of the work is that there is now sufficient evidence that climate will continue to change in the coming decades\(^2\), and that such changes must be reflected in building design if those buildings are to function adequately in the medium to long term. The complexity and form of some of these climate projections can provide a barrier to their use; probabilistic climate descriptions for multiple future scenarios are not necessarily compatible with the timescales and resources associated with real building projects. Therefore, finding a suitable compromise between accurate representation of climate projections and applicable and useable output became the main driver for this work, and the resulting tool.

With this work covering adaptation, thermal comfort, building simulation and low-carbon strategies, the topics discussed in the project are clearly, currently, fertile areas of research. The detail of this work is included in the attached LCF publications list (Appendix B), but this dissemination report will focus on the use of the research in formulating an industry-sensitive approach to estimating the performance of buildings in a future climate.

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2. Defining the problem

2.1 ADAPTATION FOR A FUTURE CLIMATE

“Adaptation”, in the context of future climate change, was described in a 2001 Intergovernmental Panel on Climate Change (IPCC) report as “Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”. In the last decade, this term has become more commonplace within both academia and industry, and applied to different sectors in different ways.

Even within the specific area of the built environment, adaptation still covers a range of different concerns, such as flood risk, effect on planning and infrastructure, water management and energy consumption. The Low Carbon Futures project focussed, mainly, on one aspect of adaptation: the potential overheating (and insufficient cooling) that might be experienced in buildings in a future climate.
It is clear that the hierarchy of concerns for those designing buildings for a future climate will be different depending on, for example, the building type, location, likely function/activity of the building and the needs of the client. It is unlikely that when planning a refurbishment for an existing dwelling that is already prone to flooding, the focus would be on thermal comfort. However, for a new office building being constructed within the urban heat island of central London, issues of overheating and (within a low-carbon context) minimising cooling loads are more likely to be of prime concern. Adaptation, in the most general sense, must therefore be a flexible approach that proposes the most suitable solutions for any given building. An adequate understanding of the building (or proposed design) and its environs is of huge importance prior to planning an approach for dealing with the implications of future climate change on that building.

Due to the nature of such a problem, the designer will be largely reliant on building modelling. Even for an existing building, where evidence might exist for a current overheating problem, the effect that a range of future climate scenarios might have on that building is impossible to discern in a purely empirical manner; and, even when trying to extrapolate real baseline building data, such empirical information (for example, hourly temperature and cooling load profiles) is not usually available in sufficient detail. This reliance on building modelling is a concern for any study of this type. It is known that, particularly when studying energy consumption, the performance gap between a modelled building and actual energy bills can be large.

However, with the above limitations in mind, a suitable building model engine should indicate to a designer how a relative change in climate might produce a corresponding relative change in the performance and internal environment of the building. The LCF project takes the approach that dynamic building software, using reliable input data, is an acceptable tool in defining adaptation scenarios based around thermal comfort. The advantage of this approach is that a feasible method might be formulated for dealing with adaptation within a commercial building design project, using well known building software, providing future climate projections can be adequately defined. Such software can also be flexible in terms of overheating definitions; while this study uses relatively simple definitions of failure, thermal comfort (and the point at which a failure in comfort might be evident) can be a relatively complex combination of immediate environment, individual perception and culture. Simulating an entire hourly temperature profile, across a year, would give the user a wide choice of thermal comfort criteria to apply to a given building.

### 2.2 Projecting Future Climate

The latest UK Climate Projections 2009 (UKCP’09) are not, in their most basic format, immediately amenable to detailed building modelling. Figure 1 compares the format of previous projections from the UK Climate Impact Programme (UKCIP’02) with UKCP’09. While UKCIP’02 gives a “deterministic” description of, in this case, external temperature, UKCP’09 replaces this with a distribution of probabilities. While this arguably represents climate models in a more accurate way, it does present a new challenge for those wishing to investigate the effect of future climate on the built environment and other sectors.

Generated values from UKCP’09 can be gathered from an online resource called the "Weather Generator", but this can be in the form of hundreds (or even thousands) of files of climate information, which would then have to be incorporated into an appropriate format for building simulation. Within an academic research project, this is resource-intensive and requires careful data management; within a commercial building project, this is completely impractical.

The Weather Generator can provide projections based on a period of time (a current baseline and seven future time periods), UK location (chosen from a 5km grid map) and greenhouse gas emission scenario (“Low”, “Medium” and “High”). In addition to the complexity of each dataset, this choice of future climate scenario can result in even more data that requires managing and processing – this

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Defining the problem

is particularly the case when downloading an hourly weather file, which is in the form of a 30-year time-series. If, for example, 100 such files are downloaded (to describe the range of probabilities for the chosen scenario), this provides the user with the equivalent of 3000 years of data (across typical metrics such as temperature, solar radiation, wind speed etc), at an hourly resolution.

One approach to this problem is to select a statistical "slice" of the information, such as a time-series of weather data that equates to a specific percentile of the probability distribution. This has been explored by another ARCC project (Prometheus), with a collated database of weather files freely available. These weather files can be applied to most building simulation projects, though they do not capture the entire spectrum of probabilities from the Weather Generator and their percentiles are based on an averaged external temperature. Such an approach is still defensible and most useful, though the user would also have to choose prior to simulation what percentiles of climate probability they wish to explore, and may still have to carry out multiple building simulations for the different climate scenarios on offer.

The Low Carbon Futures approach is to apply the simplification to the results of the building simulation, rather than the climate information. This is only possible with a method that bypasses the extensive simulation time that might be required from the equivalent of thousands of climate files. This will be described in section 3.

![UK CLIMATE PROJECTIONS](image.png)

**Figure 1 – Nature of climate projections for UKCP'02 and UKCP'09 [reproduced from5]**

### 2.3 Engaging with Industry

An important aspect of the LCF project was to gain an insight into the building industry regarding overheating in future climates and what methods were in place to define this problem. Three means of communication were adopted: questionnaires, focus groups and semi-structured interviews.

### 2.3.1 Questionnaire Responses

The LCF team devised an online questionnaire to obtain a basic understanding of the parameters considered important at various stages of the building design process. Questions were formulated to provide a feeling for how typical practice differs from best practice. To ensure a diversity of professionals including architects, electrical/

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6 Derived UKCP09 weather files from the ARCC Prometheus project (available at [http://emps.exeter.ac.uk/research/energy-environment/cee/projects/prometheus/downloads/](http://emps.exeter.ac.uk/research/energy-environment/cee/projects/prometheus/downloads/))
mechanical engineers, directors, and energy consultants, the survey link was provided through one of the fortnightly Chartered Institution of Building Services Engineering (CIBSE) electronic newsletters to its members. The 43 responses were useful in suggesting issues for further investigation.

Initially participants were asked to rate the important drivers in Heating, Ventilation and Air-Conditioning (HVAC) design. The most important drivers were

- building characteristics
- available budget
- comfort criteria, and
- CO₂ emissions.

Weighted scoring of these responses provides a method for evaluating, at a glance, the priority level of an individual. Weightings with values of 4, 3, 2 and 1, corresponding to “very important”, “important”, “least important” and “not considered” respectively, were assigned to the columns. From the results shown in Figure 2 it can be seen that “Building Characteristics” and “Climate Considerations” are the top rated parameters for an architect. For facility and technical managers, “Available Budget” and “Comfort Criteria” are highest rated, whereas “Carbon Dioxide Emissions” are the top priority for energy consultants. However, it was also clear that all professions recognised that design was based around multiple parameters (with no parameter being scored as “not considered”).

Within the questionnaire results [see Appendix B, Ref 6 for details], overheating assessments had a significantly low score, indicating its relatively low importance in the design process when compared to other factors like cost and carbon compliance. This raised a few questions, such as: Is the current prime objective of the building industry to only just comply with the standards and regulations? Is the building industry showing any signs of concern about overheating in future summers? Does the client-focus of a building project make issues such as overheating-led adaptation difficult to implement? To explore these questions, focus groups were conducted and are discussed below.
2.3.2 FOCUS GROUPS

The focus groups were structured in slightly different ways, depending on the topic under consideration and the location and audience involved. As an example of the subjects proposed within the discussions, the following questions were used to guide the conversations:

1. How big is the issue of overheating in buildings? Is it currently gaining a higher priority in the design/refurbishment of these buildings due to increased internal heat gains and the focus towards low carbon measures?
2. What consideration is given to future overheating when designing a new building or refurbishing an existing building?
3. When designing or refurbishing a building to combat overheating, what measures are typically specified to reduce the risk? What tools or software are commonly used to analyse this?
4. What climate data is used currently in the design/assessment of new or existing non-domestic buildings respectively? What do you use for future projections?
5. Probabilistic climate projections attempt to quantify the uncertainties present in climate projections; what importance do you assign to these projections?
6. Do you see future projections as an important service in that it will be attractive to designers, allowing them to make their client buildings more climate-adaptable?
7. If a tool could be provided that specified the overheating risk of a building as part of an overheating analysis based on probabilistic climate projections, what form do you think this tool should take and what kind of outputs would be preferred?

For domestic buildings, two focus groups were held with six professionals each: one in London and one in Edinburgh. Practitioners including architects, building services engineers, decision makers from housing associations and private sector house developers, were selected using UERG contacts. For non-domestic buildings the opportunity was taken to hold two focus group sessions with participants of an Energy and Sustainability network meeting, organised by the Building Services Research and Information Association (BSRIA). The diversity of roles represented by these experienced professionals include, Policy Managers, Design and Facilities Managers, Senior Engineers, Building Services Design/Simulation experts, Project Managers and Directors, along with representatives of CIBSE and BSRIA.

For the domestic sector, feedback indicated that overheating is not a prime concern in Scotland and that the probability of having some exceptionally warm days is not something that is impinging on design. It is, however, emerging as an issue in Southern England where there are more sustained summer periods and therefore an increasing demand for air-conditioning. Currently future overheating is not deemed to be a concern and this will change only if regulations and legislation drive people to consider climate change in a standardised way [see Appendix B, Ref 6].

For the non-domestic sector, overheating is deemed a problem both in the north and south of the UK. It was mentioned that in Scotland, air-conditioning in buildings is more limited compared to the South of England and it is usually fairly high specification office buildings that have mechanical cooling. Some respondents were of the view that new build projects, especially in London, will definitely have mechanical cooling, and therefore overheating can only be addressed if owners and users become aware of their carbon targets (i.e. carbon being the driver, rather than thermal comfort). Respondents also stated that most current new buildings still do not take into account future climates, with most clients taking a short-term view based on immediate economic constraints [see Appendix B, Ref 3].

The professionals that engaged with the LCF team confirmed that for a typical refurbishment, a designer tends to build in a margin based on the history of energy usage in the building rather than future climates specifically. Participants also agree that “probability”, in the context of climate projections, would only be attractive if a design method was user-friendly and intuitive, otherwise there will be a small uptake for probabilistic climate projections. For new buildings, it would force both designers and clients to think about the long-term whereas, currently, a typical client shows interest only if something has a direct impact on their productivity in the short-term. More informed clients would attempt to understand the issue and, finance permitting, would engage with risk mitigation and intervention.
In terms of outputs, average external temperature was stated as an accessible metric for a designer. Simple outputs in terms of "traffic light" indicators or an easy-to-understand display certificate, similar to an EPC, were deemed beneficial to somebody with little familiarity of the subject.

2.3.2 INTERVIEW FEEDBACK

Six semi-structured interviews were conducted for domestic buildings and nine were conducted for the non-domestic sector, with a diversity of building practitioners. In addition to confirming information gathered from the focus groups, some new questions were addressed such as:

- What are the current criteria for designing and replacing a cooling system?
- What are the key factors and safety nets to ensure that a cooling plant is not insufficiently sized?
- What are the risks of currently designed cooling plants failing to cope with increased temperatures in the future?
- How will the building industry meet the challenge of providing satisfactory comfort conditions while limiting excessive energy consumption and reducing carbon emissions at minimum operating and capital costs?

During this study it appeared that there was no standard concept of "future failure" for a cooling plant. It was expressed that a cooling plant has a life of approximately 20 years and the chances of it becoming insufficiently sized during the life time of the system is low. The most common approach is to allow for additional space in the plant room or allow the plant room to be extendable. A concern was expressed by engineers and designers that there are too many uncertainties relating to climate change and climate data modelling to take any further measures. Furthermore, a commercial building is different to a domestic building in that large-scale changes to its operation are more likely over its life-cycle. These changes are hard to predict and may include a different activity or changes in working styles, such as hot-desking or home working [see Appendix B, Ref 10].

Participants believed that clients have a major role to play when comfort cooling is requested. The design team should explain the pros and cons associated with different potential cooling systems at the scheme design stage (or whether mechanical cooling is even necessary), allowing the client to make a more informed decision on what kind of cooling system they want. It was also mentioned that sometimes a designer might investigate specifications to meet future conditions, but the cost usually takes the design back to something more suitable for a current climate. However, a large percentage of the building fee in terms of design is actually for modelling. Sizing the HVAC systems is not as labour-intensive as modelling the entire building. Producing an optimum solution demands significant modelling to test different options which is time intensive and a lot of developers/clients are not willing to pay for these modelling expenses. This is particularly important for the LCF study, where there is a danger of simulation time becoming even more onerous and unattractive to both client and designer.

2.3.3 CONCLUSIONS OF FEEDBACK

This triangulation has shown that the opinions extracted by the three modes of research were quite similar. Figure 3 shows the results in terms of the percentage of responses when investigating the most important building design parameters. Nine factors were provided to the participants of the questionnaire, focus groups and semi-structured interviews from which they had to choose what they felt to be the top three most important drivers for HVAC design. Across the three modes of feedback, most agree that "CO2 Emissions" are an important driver, being rated as both a significant current and future problem. "Building Characteristics", which includes location and the orientation of buildings on a site, thermal insulation levels, glazing type, the use of shading and exposed thermal mass in the structure to moderate temperature extremes, was also considered an important parameter. "Available Budget" was also deemed important, closely followed by "Comfort Criteria" and "Life Cycle Costs", "Climate", "Plant Space" and "Ease of Installation" were voted as the least significant parameters.

Many of the responses across this triangulation of feedback methods were relatively intuitive. It is clear that, with financial pressures on building projects, it is unlikely that vastly increased simulation exercises (and associated consultancy costs) would be welcome,
even if the client recognised the importance of climate-driven future overheating. It is also clear that the importance placed on overheating, both future and current, does change depending on whether the design team is in the north or south of the UK. There is also an understandable split between residential and non-residential building design. It also raises a question over whether the assumptions some practitioners make about the future performance of some building types (e.g. “Scottish buildings shouldn’t overheat”, “domestic buildings are probably safe from overheating”) are indeed correct.

However, it is informative to interact with the likely decision-makers of future building design projects to understand the concerns over proposed changes to the use of climate in building design. It is not enough just to demonstrate the importance of future climate and its effect on building performance; it is also necessary to provide a replicable, and robust, method that practitioners can use within their current framework that adequately accounts for likely, near-future changes to local climate. The development of the LCF tool, and formulation of a prototype approach, has been sensitive to these concerns and is described in the next section. More detail of the above qualitative approach can be found in Appendix B, references 3, 6, 16, 17, 20 and 24.
3. The Low Carbon Futures approach

3.1 THE METHOD

The basis for the Low Carbon Futures approach to assessing overheating risk is a validated emulator that correlates a range of climate variables with the outputs (namely, internal temperature and heating/cooling loads) of dynamic building simulation software. In essence, the LCF tool obviates multiple building simulations by using a quick and efficient calculation that attempts to “copy” the effect that climate has on a given building. The process requires the user to run a single dynamic simulation (such as might be produced from IES-VE\(^7\) or ESP-r\(^8\)) for a single climate file. The tool then generates a series of equations that describe the relationship between the climate variables used by the simulation and the hourly performance of that specific building (NB. A detailed account of this statistical treatment can be found in the papers listed in Appendix B – see Refs 1,2,4, and 10…). Having established this relationship between climate and building, the user can then run large suites of climate files (such as those generated from UKCP’09) through the tool. Rather than the many days that

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\(^7\) Integrated Environmental Systems Virtual Environment (IES-VE) (available at http://www.iesve.com/)

\(^8\) ESP-r building software website, ESRU group, University of Strathclyde (download available at http://www.esru.strath.ac.uk/Programs/ESP-r.htm)
hundreds of simulations might require, results can be produced in timescales of an hour (depending on the complexity of the building and number of climate files).

Figure 4 describes the whole process in simple terms. The climate data is provided by the Weather Generator, and the building simulation part of the method (right hand side of figure) is merely what a building design team might be carrying out for a conventional building analysis. The LCF tool then uses both the Weather Generator and building simulation result to generate a series of probability outputs, informing the user what the probability of “failure” (by some definition) might be for that building in different future climate scenarios. Any definition of failure that is commensurate with building simulation can be used, such as percentage of hours that the internal temperature exceeds a threshold or, for buildings with mechanical cooling, a peak cooling threshold that is not to be exceeded. Adaptive comfort approaches can also be used for more nuanced studies of overheating.

### 3.2 DISPLAYING THE RESULTS

It is clear that, when generating the equivalent of hundreds of building simulations at an hourly resolution, it is not just the calculation stage that must be manageable. The large quantity of output information must also be simplified and tailored towards an end use. The concept of probability, or risk, is one that will be familiar to many building design teams, although not always applied to issues such as overheating or cooling loads. A tool that can compare different future climate scenarios and demonstrate how a defined failure risk changes within these scenarios (and for applied adaptations), will be of clear use.

Figure 5 is an example of a probabilistic form of output from the LCF tool. It is a simple cumulative frequency graph where, for different scenarios, the likelihood of that building exceeding a threshold (based on simulation) can be estimated. In this case it can be seen that the building currently only has a 7% chance of failure (defined, in this case, as 1% of occupied hours being above 28°C) but by 2080 (using a medium greenhouse gas emission scenario) this risk has increased to 97%. In the context of the calculations used, a 7% overheating risk means that of the 100 climate files used to describe that particular scenario,
seven of them produced an hourly temperature profile that exceeded 28°C for more than 1% of the occupied year. A similar output can be produced for the same building with various adaptations applied, where the adaptations (such as building shading, reduced internal heat gains, increased or night-time ventilation) would have to be simulated again through the dynamic simulation software and the LCF tool re-run.

These probabilistic plots are useful for comparing different degrees of failure across several scenarios, but it is also useful to have a summary of these scenarios that relate to a specific failure threshold. Figure 6 demonstrates an output from the LCF tool that aims to do this. This "Risk Matrix" provides a more immediately intuitive representation of how that building is predicted to perform different climate scenarios and adaptation choices. The designer may then make a judgement as to an acceptable future risk; while designing to a zero future overheating risk may not be deemed cost-effective (depending on the measures required), an overheating risk of 10% may be seen as sufficient and an acceptable compromise on cost and future building comfort.

<table>
<thead>
<tr>
<th>Current climate</th>
<th>No Adaptation</th>
<th>With adaptations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030, Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030, Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050, High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050, Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2080, High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2080, Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2080, Low</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

% chance of failure
- 81-100
- 61-80
- 41-60
- 21-40
- 0-20

3.3 CASE-STUDIES

The tool has been applied to various case-studies, four of which are detailed in Appendix A and summarised below. These are presented here to demonstrate the LCF methodology, but should not be used for drawing stock-wide (or sector-wide) conclusions about the entire UK building stock. However, combined with additional research, they provide an indication of the kind of impact that adaptation strategies might have on some buildings, and how a design team might decide if such adaptations are necessary. For simplicity, the case-studies show the result of multiple combinations of adaptations applied at the same time, but the designer could apply these adaptations step-by-step if the individual effect of each measure was to be discerned.
3.3.1 Filled cavity-wall detached house (CS1)

Case Study 1 (CS1), a fairly typical UK dwelling, is not expected to have a particularly notable overheating problem, even though it is based in the south of the UK (this has also been simulated for an Edinburgh climate—see Appendix B Ref 2). However, the effect of climate on the non-adapted building is quite prominent, with a very high risk of overheating for all 2080 scenarios. Therefore, this case study appears to have a risk that is driven by climate change and not current overheating. This absence of a high overheating risk in the current climate potentially reduces the likelihood of solutions (i.e. adaptations) being installed.

A combination of external shading, reduced internal heat gains (through improved lighting and appliances) and changing the window-opening schedule (to allow night-time purging of heat built up during the day in a way that might be acceptable for a dwelling) reduces the emerging risk significantly for 2030 and 2050 scenarios, but a considerable overheating risk is still predicted for the 2080 scenarios. This is based on an overheating definition of percentage of occupied hours above 28°C, though high night-time bedroom temperatures may also trigger adaptation [see Appendix B, Ref 1].

3.3.2 Solid wall house with low-carbon refurbishments (CS2)

If the concept of climate change adaptation is to become commonly applied to existing dwellings then it is likely to be integrated with attempts at refurbishing homes to reduce carbon emissions. Through appropriate specification, many measures for reducing carbon emissions can be simultaneously effective at improving thermal comfort. However, as part of a major low-carbon retrofit, it is more difficult to assess the effect that a combination of varied building fabric and ventilation measures might have on thermal comfort, particularly when future climate projections are applied to the assessment.

A sensible approach to this problem would be to ensure that major refurbishments of this type are climate adaptive; that is, some form of analysis is carried out to ensure that they do not increase the likelihood of overheating in

The Low Carbon Futures approach
3.3.3 PRIMARY SCHOOL (CS3)

It could be argued that industry is less experienced in dealing with overheating in school buildings when compared to the rest of the non-domestic sector. This is for two reasons. Firstly, there have been a large number of new (or refurbished) school buildings in the last ten years in the UK due to building programmes (such as Building Schools for the Future), and so our ideas of what a school building might be has changed in a relatively short space of time. Secondly, and just as importantly, the internal activity of a typical modern school involves substantially more computer and electronic equipment than an equivalent school of the past. This has a significant effect on internal heat gains and, as a result, the HVAC services required to deal with this. Just as, in the 1970s and 1980s, offices became warmer, or required more cooling as more IT equipment was introduced, so have schools in the last decade or so.

If we introduce a changing climate into this problem then the need for an adequate and comprehensive approach to design becomes clear, hence the choice of a school building as a case-study. CS3 is a simple one-storey primary school, constructed in line with 2000 UK building regulations. The corresponding U-values are therefore reasonable, although not best practice compared to a new school building. The school is divided into distinct zones of activity within the building (e.g. kitchens, assembly areas, teaching spaces etc) based on recommended design data11.

While various overheating definitions exist for schools, for the purposes of demonstration, this case-study is assessed against Building Bulletin 10112. This publication suggests that teaching areas should not exceed 28°C for more than 120 occupied hours per year [NB. This threshold is also accompanied by secondary qualifications concerning maximum allowable temperature and temperature differential between inside and outside – these are not considered here, but could be integrated into the tool]. The case-study is estimated to have a very high risk of exceeding this threshold for all climate scenarios; however, through a combination of adaptations, this risk is almost eliminated for those same climates. These adaptations include increased natural ventilation provision (to a design target of 12 l/s/person), reduced internal heat gains, and external shading above south-facing glazing. While this strategy appears successful, it should be mentioned that this assumes that the ventilation target can be met non-mechanically, and the current rise in internal heat gains is tempered, and eventually reversed, by an improvement (and appropriate selection) of low-energy technologies (see the Tarbase project13 for a detailed description of these types of technologies and associated internal heat gain profile).

3.3.4 MECHANICALLY COOLED OFFICE (CS4)

As the LCF tool estimates building thermal performance every hour, it is equally adept at emulating cooling load profiles and temperature profiles. To demonstrate this application, CS4 is a model of a mechanically cooled office (also used in the Tarbase project13) in London (though, again, this building has been simulated for various UK locations with other parallel studies). For such a building, the concept of “failure” might be quite different to a building without mechanical cooling. As cooling plants tend to be significantly oversized, it is very unlikely that this type of building will overheat due to climate change. With cooling systems replaced every 20 years or so, the prospect of having an under-sized system as a result of a changing climate is even less likely. Rather, the plant will be used more often and be required to meet larger peak cooling loads. In some cases, this might result in the plant margin (i.e. the difference between peak cooling requirement and size of the plant) becoming low enough to cause concern for the building designer, even if there is not really a possibility of under-cooling the building. However, a more common concern, particularly as low-carbon targets become more challenging, might be the increased energy consumption (and carbon emissions) associated with cooling in a warmer climate.

A failure threshold, based on this metric, is therefore somewhat subjective. A designer might be interested in adaptations that will stop the cooling requirement increasing by any amount in the future, or a more flexible

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threshold could be proposed that allows for a small (e.g. 10%) cooling increase; the LCF tool can allow the user to define this threshold based on the intentions for that specific building. Although not demonstrated here, the tool also has the potential to perform the same analysis for heating loads — therefore, if carbon emissions were being used as the main metric to judge the change in a building, the combined heating and cooling energy consumption could be included in the analysis. This first step to a probabilistic analysis of future building energy consumption is outside the remit of the LCF project, but the potential of this is currently being explored by UERG.

To generate a nominal failure threshold, the maximum annual cooling requirement of the baseline building (in MWh/yr), in a current climate, is used as a point of reference. All future climate and adaptation scenarios are then compared to this — the designer can then see the likelihood of exceeding this threshold, and make a judgement of what level is too high. So, for the risk matrix of CS4 in Appendix A, the output is showing the probability that any future scenario will produce a building cooling requirement that is higher than the maximum (i.e. 100% percentile) estimate of the baseline, pre-adapted building in a current climate. Based on this fairly rigid definition of cooling failure, the building is found to have a high probability of failure for all future climate scenarios.

Cost-effective solutions of reduced internal heat gains (based on near-future lighting and equipment suggested by the Tarbase project14) and external shading on all south-facing glazing are investigated as passive adaptations consistent with a low-carbon approach. These adaptations successfully counteract this increased cooling for all future scenarios (with only a small risk projected for 2080, high emission), suggesting there should not be a need for increased mechanical systems.
4. Conclusions of the LCF project

The Low Carbon Futures project has generated a tool that emulates the effect of climate on building simulation, allowing building performance to be estimated in a wide range of climates (such as those generated by UKCP’09) within a timescale that is achievable for most building design teams. Avenues will now be explored for expanding the use of the tool and applying it to more building projects, allowing for a more meaningful approach to climate-adaptive design.

The overall recommendations and conclusions of the project are:

- Complex descriptions of climate, such as UKCP’09, can be used to assess climate-driven overheating and heating/cooling load variations with appropriate building software. A range of methods have been proposed for dealing with this from various projects, some through the Adaptation in a Changing Climate Network.
- Statistical processing of complex climate information can produce relatively simple results; the complexity of the input does not need to complicate the output providing an appropriate vehicle is chosen to interpret the results.
- Translating the term “probability” to a concept of “risk” will allow future building performance analyses to have parallels with existing risk analyses that a building design team might already be carrying out.
- Adaptation measures, and their effects, should be specific to a building and any building software should be sensitive to this fact. As with low-carbon design choices, the heterogeneity of the UK building stock should not be ignored.
- The concept of adaptation should be applied to all low-carbon refurbishments (and, for new buildings, low-carbon building design choices) to ensure that the building will perform adequately in the future and not require further action. Fundamentally, a low-carbon building should be adaptable to climate change.
- The collation and management of both climate and building performance data must produce an output that is of value to the clients of building design teams; demonstrating how adaptive design choices increase the robustness of that building in a changing climate, in relation to both comfort and energy consumption, should be a key message to the potential user of that building.
- The importance attached to climate change adaptation varies with location and sector. London-based respondents seemed to be aware of overheating risks in both domestic and non-domestic sectors, though the major concern was the latter. In Edinburgh-based studies, the concern was notably less apparent in both sectors, despite evidence suggesting that overheating was already not uncommon in the non-domestic sector. In Scotland, there is a tendency to ignore temperature-based climate adaptation issues due to other problems (such as flooding, land-use and agriculture) being seen as more imminently threatening.
- Buildings overheat (and have high cooling loads) for a range of reasons, with many offices and schools suffering from high internal heat gains from IT equipment and lighting. It is therefore true to say that not all overheating/cooling load problems are driven by climate change alone. However, climate change can clearly exacerbate this problem, such that design choices for improving comfort might be inadequate if future climate is not accounted for. The role of adaptation is to quantify this relative change in risk due to climate, even if an overheating/cooling problem already exists in that building.
The LCF project was concerned with the application of building modelling but, as with model predictions of energy consumption, our understanding of temperature profiles of buildings can only be improved by more extensive monitoring of real life case-studies. While future predictions, by definition, need some form of modelling to future-cast that scenario, models are far more powerful when supplementing empirical data, not replacing it.

The LCF tool, using novel emulation techniques, provides a means of applying a wide spectrum of climate scenarios through dynamic simulation to produce probabilistic building performance outputs of benefit to both building designer and client. When using a future climate resource, such as UKCP'09, this is a particularly effective method of modelling adaptation measures.

**ACKNOWLEDGEMENTS**

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Conclusions of the LCF project
CS1 – FILLED CAVITY-WALL DETACHED HOUSE

Building Information

Total Floor Area: 144m²
Construction: Filled-cavity wall masonry with insulated loft and double-glazing
Typology: Detached
Occupants: 2 adults, 2 children
Location: London
Simulation package used: IES-VE

Construction details

Floor U-value: 0.25W/m²K
Wall U-value: 0.37W/m²K
Roof U-value: 0.20W/m²K
Window U-value: 2.1W/m²K

Ventilation regime: Natural with window openings (with average infiltration rate of 0.7ac/h)

Overheating definition

1% of occupied hours above 28°C constitutes overheating (whole house average)
Building is calculated to be occupied for 6656 hours per year (16hrs per weekday; 24hrs per weekend day)

Adaptation Scenarios

Window-opening schedule during night-time overheating. External shading above windows installed and internal heat gains reduced by 25% (relating to more efficient appliances and lighting)

Occupancy profiles (1 = Occupants present; 0 = None present)
Although the dwelling is unlikely to overheat for a current climate, the increased risk of overheating due to future climate change is considerable. However, basic adaptations are shown to offset this potential increase for the near decades, with more extensive adaptation possibly required for longer-term timescales.
CS2 – SOLID WALL HOUSE WITH LOW-CARBON REFURBISHMENTS

Building Information
- Total Floor Area: 110m²
- Construction: Solid-walled with unheated, pitched roof, single-glazing
- Typology: Semi-Detached
- Occupants: 2 adults, 2 children
- Location: London (as modelled)
- Simulation package used: IES-VE

Construction details
- Floor U-value: 0.6W/m²K
- Wall U-value: 1.7W/m²K
- Roof U-value: Modelled as unheated, uninsulated loft
- Window U-value: 5.5W/m²K

Ventilation regime: Natural with window openings (with average infiltration rate of 0.7ac/h)

Overheating definition
- 1% of occupied hours above 28°C constitutes overheating (whole house average)
- Building is calculated to be occupied for 6656 hours per year (16hrs per weekday; 24hrs per weekend day)

Adaptation Scenarios
- Refurbishments focused on low-carbon interventions, with adaptation assessment made on these refurbishments.
- “Improved” refurbishment stage includes external wall insulation, loft insulation, floor insulation, double-glazing and basic draught-proofing.
- Advanced “Tech Improved” refurbishment stage, in addition, increases both wall and loft insulation, triple-vacuum glazing, advanced air-tightness measures with MVHR (heat recovery 80%). For more details see www.calebre.org.uk

Occupancy profiles
- Occupancy times and W/m² lighting/appliance profiles similar to case-study CS1.

Building Pre-retrofit

![Graph showing probability of occurrence vs. % of occupied hours > 28°C]

- Current Climate
- Medium Emission - 2030
- Medium Emission - 2050
- Medium Emission - 2080
LCF Probabilistic overheating results

**Building with “Improved” refurbishment**

Verdict

The current overheating risk is negligible, and should not be of concern unless looking at a much longer timescale. Even at this 2080 timescale, the low-carbon refurbishments (particularly the controlled ventilation and reduced solar gain) are likely to reduce this overheating risk.

**Multi-scenario risk analysis**
CS3 – PRIMARY SCHOOL

Building Information
- **Total Floor Area**: 840 m²
- **Construction**: Single storey brick/blockwork with double glazing
- **Typology**: Primary school
- **Occupants**: 7 full time staff, 150 pupils
- **Location**: Edinburgh
- **Simulation package used**: ESP-r

Construction details
- **Floor U-value**: 0.25 W/m²K
- **Wall U-value**: 0.56 W/m²K
- **Roof U-value**: 0.22 W/m²K
- **Window U-value**: 2.75 W/m²K
- **Ventilation regime**: Natural with window openings (with average infiltration rate of 0.3ac/h)

Overheating definition
Based on “Building Bulletin 101” definition for schools, suggesting no more than 120 occupied hours above 28°C in a teaching area

Adaptation Scenarios
- Increase max. natural ventilation from 8 to 12l/s/person. External shading above windows installed and peak internal heat gain reduced by 20% (relating to more efficient appliances and lighting)

Occupancy profiles (1 = Occupants present; 0 = None present)

![Graph showing occupancy profiles for Weekday and Weekend](image)
Verdict

The building, despite being located in Edinburgh, is already at a high risk of exceeding the overheating definition for a current climate. Therefore, while the future climates also have high overheating risk, this can’t be said to be driven by climate alone. The adaptations are projected to eliminate this risk almost entirely.
Building Information
- **Total Floor Area**: 4000 m²
- **Construction**: 1980s, concrete panel building with double-glazing
- **Typology**: Office
- **Occupants**: 286 full time staff
- **Location**: London
- **Simulation package used**: ESP-r

**Construction details**
- Floor U-value: 0.27 W/m²K
- Wall U-value: 0.65 W/m²K
- Roof U-value: 0.87 W/m²K
- Window U-value: 2.75 W/m²K
- Ventilation regime: Mechanical ventilation (with average infiltration rate of 1.0 ac/h). Cooling from 2 x 194kW chiller units with associated fans and pumps

**Excessive cooling definition**
Building assumed not to “overheat” due to air-conditioning but failure is defined as the maximum (100% percentile value) projected cooling requirement in the baseline climate. The percentage probability of the future scenarios being higher than this maximum are therefore used in the output.

**Adaptation Scenarios**
External shading above windows installed and internal heat gains reduced by 60% (relating to more efficient appliances/equipment and lighting)

**Occupancy profiles** (1 = Occupants present; 0 = None present)

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LCF Probabilistic overheating results

Building without adaptation

Verdict
The office has a high probability of exceeding the failure threshold for all future climate scenarios. However, the applied adaptations demonstrate this risk can be, almost, eliminated with relatively low cost measures. This will also further reduce the need for larger cooling systems in the future, while making the building more robust to any changes to internal activity. A less rigid failure definition, increasing the allowance for higher cooling, would reduce the need for adaptation further.
Appendix B  – List of Low Carbon Futures project publications

ACADEMIC JOURNALS


CONFERENCES


**OTHER**
