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Probabilistic future cooling loads for mechanically cooled offices

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ABSTRACT

Probabilistic future climate projections provide a challenge to building modellers aiming to quantify potential cooling loads and energy use of simulated buildings. The scale of information means that conventional simulation methods might not be suitable. This paper applies an emulation tool, developed by the Low Carbon Futures project, to provide probabilistic assessments of future cooling loads for a case-study office building. The concept of future building failure, as applied to a mechanically cooled building, is discussed and the use of the tool in such a circumstance overviewed. A range of information that might be gained from the tool, such as hourly cooling loads, coolth requirement and electrical consumption, are presented and the use of such metrics discussed.

1. Introduction

Heating, ventilation and air conditioning (HVAC) related energy consumption has been rising in recent years throughout Europe; particularly Southern Europe but also in the UK [1,2]. According to the UK's Carbon Trust 10% of the UK's commercial floor space was mechanically cooled in 1994. An Australian study undertaken to understand the implication of global warming on existing air-conditioned office buildings (that are designed under current climate conditions) revealed an almost linear correlation between the increase of average external air temperature and the increase of building cooling load and building total energy use [3]. These increases in cooling load vary significantly (from 2% to 47%), depending on the assumed future climate scenarios, as well as the different locations.

In the non-domestic sector, it has been estimated that the annual energy consumption of air-conditioning in the UK in 2000 was 11.3 TWh, with a projected rise to 20 TWh in 2020 [4]. Due to quite rapid changes in operation and technology, it could be argued that UK non-domestic buildings in particular are not always optimally designed for the activity within, particularly in relation to summertime thermal comfort. For example, offices built in the 1960s would not usually have been air-conditioned or necessarily designed with overheating as a prime concern. With the rapid increase in IT equipment in the following decades, these buildings could not cope with the large amount of heat generated within the building and so either provided poor thermal comfort, or were retrofitted with some form of cooling unit. Likewise, school buildings over the last decade in the UK have undergone a change in internal activity led by a growth in IT equipment (such as electronic whiteboards). Along with changes in the design of new build schools (to reduce space heating energy usage), this has led to some reports of overheating in buildings that, in previous decades, would have had relatively low risk of high internal temperatures outside the peak summer period.

Part of the problem with the above examples is that it is very difficult to predict long-term changes to the internal activity of a specific building. While internal heat gains have the potential to reduce in those buildings that have reached some kind of saturation of IT equipment, a designer today would not have any indication of how changes within the building over several decades might make initial assumptions relating to thermal comfort obsolete (whether the effect would be to make the building warmer or cooler). In addition to variables inside the building, it is expected that climate will also change significantly within the lifetime of a building designed today. While projecting future climate is, similarly, a challenge with inherent uncertainties, there are sources of information that provide some indication of how climate might change for specific scenarios over given time periods. There is therefore an opportunity to design a building, and associated building services, with a future climate in mind.

The approach of a building designer in specifying a mechanical cooling system, and their understanding of the energy that such a system might be use, will usually be informed by design guides based on current climate information. This information might include single design values of solar radiation and ambient temperature for a specific location (along with building design and daily usage estimates). For those interested in how such systems might perform in the future (within the lifetime of both the building and the cooling system), some general advice can be obtained [5] that might indicate, for example, near extreme values for future climate scenarios.

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As will be discussed, the latest UK climate projections [6] are less immediately useable for such applications due to the complexity and scale of the available data. They consist of a range of equally probable datasets (represented by thousands of different climate files) for different emission scenarios, timelines and locations. This paper applies a tool developed by the Low Carbon Futures (LCF) project [7] that integrates probabilistic climate information into dynamic building software. The specific focus will be on cooling loads, and the use that the tool might provide for a building designer aiming to estimate the effect of climate change on such loads.

2. Concept of failure in a mechanically cooled office

Qualitative investigation forms an important aspect of the LCF project and involves interaction with building professionals [8,9] to obtain information on current design procedures and the applicability of the proposed tool. For the present study, interactions were carried out with building practitioners from local authorities and leading global firms of consulting engineers, designers, planners and technical specialists to collate feedback on the issues of designing cooling systems. Participants were engaged in a focus group and six face-to-face interviews were conducted in England and Scotland.

The purpose of these interactions was to address questions such as: what are the current criteria for designing and replacing a cooling system? What are the concerns and drivers behind such decisions? 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? What measures are typically specified to reduce this risk? How will the building industry meet the challenge of providing satisfactory comfort conditions by limiting excessive energy consumption and reducing carbon emissions at minimum operating and capital costs? Previous dissemination by the project team has discussed these qualitative methods and results in more detail [8], with a summary discussion of the findings now provided below. The below points are therefore not presented as universal facts, but do represent the opinions of the participants of the study.

The work suggested areas of particular interest with regards to the design of cooling systems. A typical approach for designing a cooling plant in the UK is to size the system against worst-case summer conditions, keeping the internal space at a recommended indoor temperature. Often, a 10% over-sizing factor is applied to the above, which provides the building services engineer with additional confidence in the system meeting even the most extreme requirements. Over-sizing of cooling plants is therefore quite common, to ensure that the building does not fail fairly static comfort requirements during the summer period (e.g. cooling to at least 23 °C). This approach is generally driven by the fear of losing business due to consequential loss of credibility in the marketplace arising due to client dissatisfaction. The amount of over-sizing, however, could vary from client to client where some clients object to unnecessary plant over-sizing as it is expensive to install and costs more to run and maintain. This is typified by the comments provided by one participant:

> We generally make allowance for an additional 10–15% capacity for plant start-up/future expansion, but this can vary according to client requirements.

Participants of this study believe that there needs to be flexibility in design. To minimise thermal discomfort a lot of emphasis needs to be put on the actions that users can take to make things more comfortable for themselves. Working in cooler parts of the building, taking breaks and wearing lighter clothing all can help to avoid using mechanical cooling. A minority of participants saw a significant potential in encouraging personal adaptation to cope with an overheating situation. For instance they believe that, like Southern Europe, 26 °C might be an acceptable internal temperature. As one participant said:

> I believe there is room to increase the internal conditions rather than increasing the capacity of the cooling plant. It is not something that people will straightaway adapt themselves to in the UK [to 26 °C]. But I can see there is the potential to educate people

Although the above point is not included in the application of the tool, it is reasonable to suggest that people will not react to increased temperatures in a linear and simple way, and this will have clear effects on the cooling loads of a future office.

During this study it appeared that there is no standard concept of "future failure" for a cooling plant. It was expressed that a cooling plant has a life of about 20 years and the chances of it becoming insufficiently sized during the life time of the system is low. After replacement, an engineer would recalculate the loads based on the current guidance for that period and potentially allow for other changes (such as a different activity within the building due to change of business). Some participants were of the view that clients would only show interest in this if it had a direct impact on their productivity, but this type of assessment would not extend to too far in the future. 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 make any further measures. Furthermore, a commercial building is different to a domestic building in that changes to its operation are quite likely over its life-cycle. These changes are hard to predict and may include a different working purpose or changes in working styles such as hot-desking or home working.

It was agreed, however, that an optimised solution depends on how well the design team works together and is a combination of architecture and engineering. Disconnection between the architects/designers and the building services engineers can be a problem, where engineers service buildings that have already been designed by the architects. Such a situation is not likely to produce an optimally designed building for a current climate, let alone a future one.

Participants believed that clients have a major role to play where comfort cooling is requested. The design team should explain the pros and cons associated with different potential cooling systems at the scheme design stage to allow them to be best placed to make a more informed decision on what kind of cooling system they want. It was also mentioned that sometimes a designer aims to meet future conditions, but the cost usually takes the design back to bare basics. 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. Morton et al. [10], in their study about exploring beliefs about climate change, have also came across similar beliefs where clients see the sustainable and low energy solution as a costly approach and still often want to spend the minimum time and money to achieve a suitable building to meet current regulations.