Climate Change Risk Management for Buildings

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Abstract

This paper reports on research that aims to quantify the thermal risks that climate change poses towards buildings, allowing a discussion about the acceptability of these risks. The work aims to ultimately establish risk threshold values, helping the facilities management process. The paper reports on two different but interrelated research activities: (1) work in the field of building performance simulation, where computer models are used to predict the thermal behaviour of buildings under present and future conditions, and (2) a recent series of workshops/expert panels that were organised to discuss initial findings with actors in practice as well as academia. The results show that building simulation can indeed be used to predict future behaviour, but that extreme care is needed in preparing the detail of the future scenarios that are being investigated. This covers non-trivial issues like uncertainties in renovation/intervention activities, changing heat load and user profiles, thermal comfort control assumptions, and system degradation. Without sufficient attention for detail uncertainties over the simulation input would render the outcomes useless. The expert panel sessions confirmed the need to involve stakeholders in the building operation / facilities management process in the climate change impact research; without these stakeholders it would be nearly impossible to identify the key performance indicators that need to be investigated. Overall, the work demonstrates the limits of a purely computational approach to studying the risk posed by climate change to the thermal performance of buildings, stressing: (a) the need to study specific situation in detail through actual case studies; (b) the need to involve stakeholders in those studies; and (c) the need for further research in the 'soft' factors that influence the facilities management process.

Keywords: climate change, risk, thermal performance, facilities management, simulation

1. Introduction

Buildings are an area where climate change poses risks. Most buildings have a long life time, which means that buildings will be in place long enough to experience the slow process of climate change. Moreover, the thermal performance of most buildings is strongly intertwined with the climate in which the building operates, which is a dominant factor in heat flows due to transmission and ventilation. Also note that climate conditions are a prime factor in the applicability of some of the heating, ventilation and air conditioning systems applied in buildings such as summer night cooling or natural ventilation.

Research in the adaptation of buildings to a changing climate is only recently appearing. In the UK the seminal work in the discipline is the report by CIBSE TM36 on Climate change and the indoor environment: impacts and adaptation (Hacker et al., 2005). Examples of more recent work in the field include the studies by Crawley (2008), Jenkins et al., (2009) and Coley and Kershaw (2010). While these studies provide valuable insights into how buildings will cope with changes in climatic conditions, they are not yet addressing the actual management of buildings subject to climate change by building owners, occupants and facilities managers. Such management will weigh risks and investments, defining the building operation and deciding upon interventions in the building services, fabric (infill, cladding) and structure.

In general risk can be calculated according to the following, universal formula:

$$RF = Pf \times Cf \qquad (1)$$

Where RF = Risk Factor, Pf = Probability of failure, and Cf = Consequence of failure. Calculation of RF allows to set thresholds to identify low (> x), medium (> y) and high (> z) risks, and highlight those risks requiring further attention.

This paper describes research that aims to quantify the thermal risks that climate change poses towards buildings, allowing a discussion about the acceptability of these risks. The work aims to ultimately establish risk threshold values, helping the facilities management process.

2. Methodology

The paper presents work in two related lines of work: building performance simulation research, and expert panel workshops.

The international building research community has been studying the thermal behaviour of buildings since the energy crisis of the 1970s. Since then, it has developed a large number of methods and software tools to analyse and optimise thermal building performance. These tools are now used in building engineering on a regular basis. For good overviews of the related field of building performance simulation see Malkawi and Augenbroe (2004) or Clarke (2001). Building simulation is the only available methodology to predict the impact of future climate conditions on the thermal behaviour of buildings in detail, since it can conduct a ‘virtual experiment’ in the computer that combines climate predictions with physical models that represent how building will respond to these future conditions.

However, work that aims to study the management of buildings and building systems (like for instance building services and building fabric) also needs to take into account the operational context of facilities management. To cater for this need, a number of expert panel workshops have been organised to discuss simulation results with colleagues from practice and academia. The format of these workshop sessions was a half hour presentation on the building simulation studies, followed by 45 minutes of discussion and feedback from the audience on the ongoing research.

3. Building simulation studies

Building performance has been based on the use of recent releases (V3.0-V4.0) of EnergyPlus. EnergyPlus is a well documented and validated simulation engine, for documentation see the EnergyPlus website.

Simulations have been carried out for two buildings: a theoretical reference building, and an actual existing building.

The theoretical reference building is based on the specific case as defined by CIBSE TM36 (Hacker et al., 2005, pp.42-43) “O2: Modern mixed-mode office”. This case represents a modern medium-sized office building with mechanical mixed-mode ventilation and low-energy active cooling. It is a three-storey office with a floor area of 3864 m2, as depicted in Figure 1. The building is well insulated, with overhangs to shade windows in summer, and has ample thermal mass for heat storage. Schedules for lighting, equipment and occupancy are according to the British data for an open plan office as described in the National Calculation Method (NCM, 2009). In winter, mechanical ventilation with heat recovery is used to provide the air for the building, with all 100% sourced from outdoors. In summer, there are two ventilation modes: natural and mechanical. The natural ventilation (free-running) mode is used when the indoor operative temperature is below the cooling set point (below 25^{o}C using the static thermal method, below a variable threshold when using the adaptive thermal method). Otherwise, mechanical ventilation with an indirect evaporative cooler is used to provide cooling for the building. This evaporative cooler is located in the return air streams to provide sensibly cooling for the building without increasing its absolute humidity (CIBSE, 2005). In the simulation, the natural and mechanical systems are in changeover operation mode, which means they do not operate at the same time. The mechanical ventilation system is also used for night cooling in summer. It is noted that this office building may have overheating problems as the indirect evaporative cooling has only limited cooling capacity (ASHRAE, 2008). More detailed descriptions of this office can be found in literature, see Hacker et al. (2005) and Holmes and Hacker (2007).

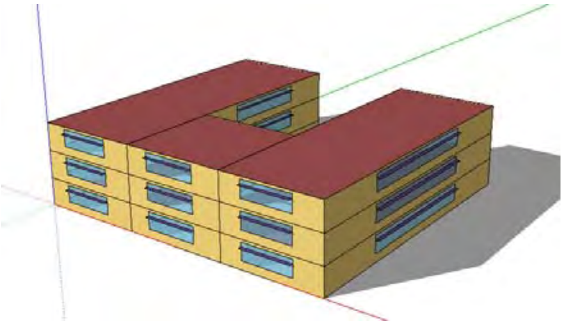


Figure 1: 3-D View of the CIBSE TM36 O2 Reference Office

The TM36 O2 Reference office has been studied using the UKCIP02 climate change scenarios as released in 2002. These have become the standard reference for climate change research in the UK, accounting for four emission scenarios (low, med-low, med-high, and high). Three 30-year time slices have been used: 2011-2040 (2020s), 2041-2070 (2050s) and 2071-2100 (2080s).

Within the simulations, a range of uncertainties has been covered by means of 2-D Monte Carlo analysis. Distinction has been made between aleatory uncertainties (natural variation in the system) and epistemic uncertainties (variation due to lack of knowledge), with the epistimic factors being represented on the outer loop of the Monte Carlo simulations, and the aleatory on the inner loop. In total, 30 epistimic factors and 80 aleatory factors were combined, needing 7280 individual EnergyPlus simulation runs. Results are presented as Cumulative Distribution Functions (CDFs); figure 2 shows the outcomes for predicted annual cooling energy. Similar graphs have been created for heating energy use and overheating.

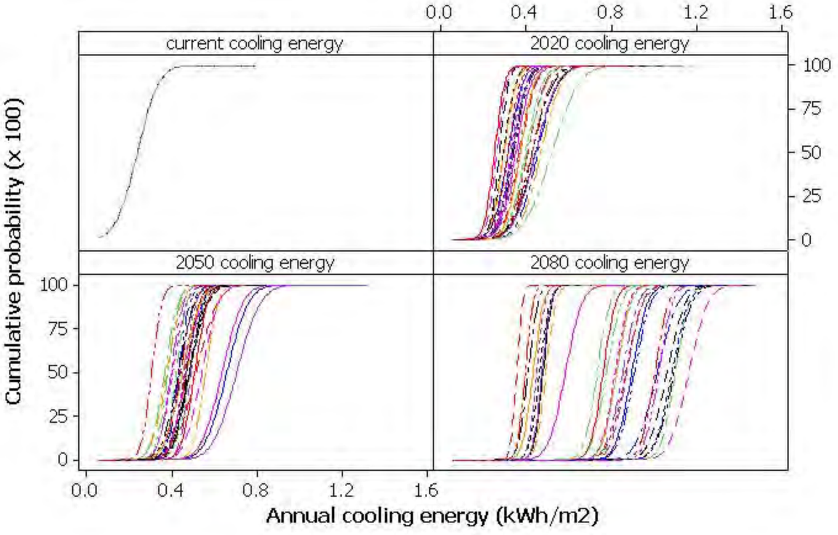


Figure 2: CDFs for annual cooling energy use

In a separate simulation study, the impact of thermal comfort modelling on the predicted behaviour under climate change has been analyzed. This is a relevant study, as it is known that humans adapt to the thermal conditions, whereas standard comfort control settings in most building simulation tools are static. Results show that overheating risks for the 2020s obtained using a static might increase by a factor 10; whereas overheating risks for that same time horizon obtained with an adaptive model show an increase of less than a factor 2. Further detail of this work can be found in de Wilde and Tian (2010).

Another issue taken into account in the simulation study is intervention. Over the long lifetime of the building, it is likely that building services and building fabric will see multiple upgrades. Three types of intervention scenarios have been investigated: a base-case scenario, where properties of systems and fabric maintain constant over time (a 'like-for-like' replacement); case A which represents moderate investment in the building and a relatively slow upgrading of building energy efficiency; and case B which represents more aggressive investments in upgrading the building energy efficiency. For cases A and B intervention times have been assumed based on literature review; in between interventions systems and fabric properties are again taken to be constant.

A probabilistic simulation of the TM36 O2 Reference office, taking into account a range of uncertainties, can yield the probability of occurrence of indoor air and surface temperatures throughout the building. This can be mapped into the probability (Pf) in formula (1). This then can be combined into consequences (Cf) to obtain risk, using the same formula. To this end, EnergyPlus results have been linked to a formula that relates said temperatures to a predicted 'relative work performance', using work by Fisk and Seppänen (2007). Typical results are depicted in Figure 3. Note that predicted relative work performance is adding a range of assumptions on top of the temperature probability, and that hence the projection of relative work performance is much more coarse than the prediction for temperatures in itself.

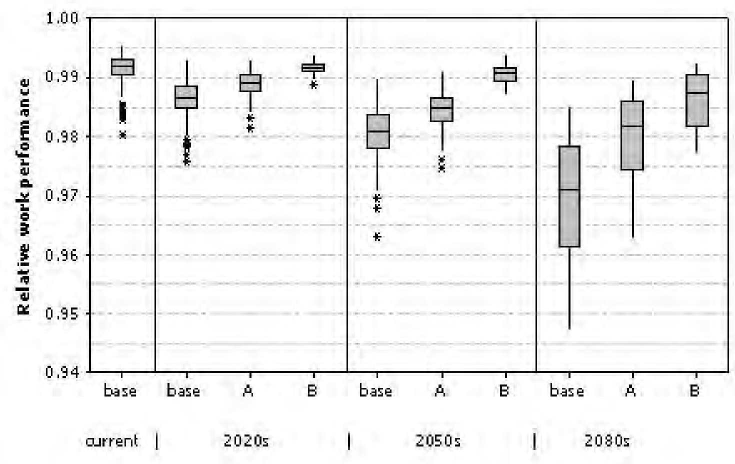


Figure 3: Predicted relative work performance for the TM36 O2 Office

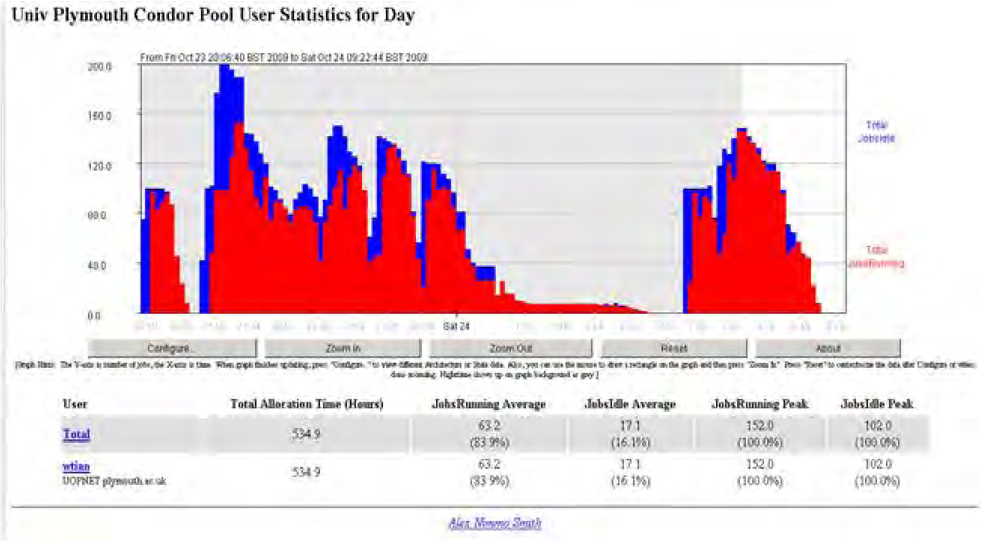
The results for predicted relative work performance demonstrate the limits of using a theoretical reference building. While overall results are interesting, indicating a risk of a reduction of work performance of about 3%, there are issues that the research team would like to discuss with the stakeholders in the building. For instance, is one aggregate relative work performance figure a relevant performance metric, or would an actual facilities manager prefer a higher spatial resolution? Note that overheating effects are more likely to occur on the top floor, and in the southwest-facing rooms/zones of the building. Also, is relative work performance in itself a valuable metric for facilities management, or would professionals prefer the original underlying data in terms of temperature series and overheating hours?

The actual existing building is the Roland Levinsky Building, a flagship facility at the authors' campus. This provides good access to the people involved in the design, engineering, construction and FM processes (client, expert consultants, contractors, estate department) and a wealth of related documents. Furthermore, further information on building details, occupancy patterns etc. can be obtained on-site whenever needed. The building is a multi-purposed facility for use by staff, students and the general public, delivering a home for the Faculty of Arts along with theatres, a cafe, generic teaching spaces and administration services areas. It has about 13,000 m^2 of floor space and is nine-storey high, see Figure 4. It comprises a reinforced concrete frame with post-tensioned slabs, long span beams and a steel roof structure. The copper cladding wraps from the two-storey west elevation and forms the complex roofs and eastern facades for the eight-storey elevation. The north and south facades are entirely glazed with low SHGC (solar heat gain coefficient) windows. Mechanical ventilation has been implemented in this building because of the noise and pollution in the city centre. Ventilation is controlled by variable speed fans with a supply air temperature of 19^{o}C. Multiple air handling units allows varying occupancy schedules for different space uses, such as classrooms, offices and theatres. The air-cooled chillers provide cooling water to coils in the air handling units and fan coil units. Gas-fired condensing boilers supply hot water to heating coils, a perimeter trench system and wall-mounted radiators.

Figure 4: Photo of the Roland Levinsky Building at the University of Plymouth campus

The complex geometry of the Roland Levinsky Building was modelled with the OpenStudio (Sketchup) plugin for EnergyPlus. The final building model has 105 zones. Two versions were made regarding services in the model: one with simplified services, sized as per heating demand, and one a detailed HVAC (heating, ventilation and air conditioning) system representing the actual system layout.

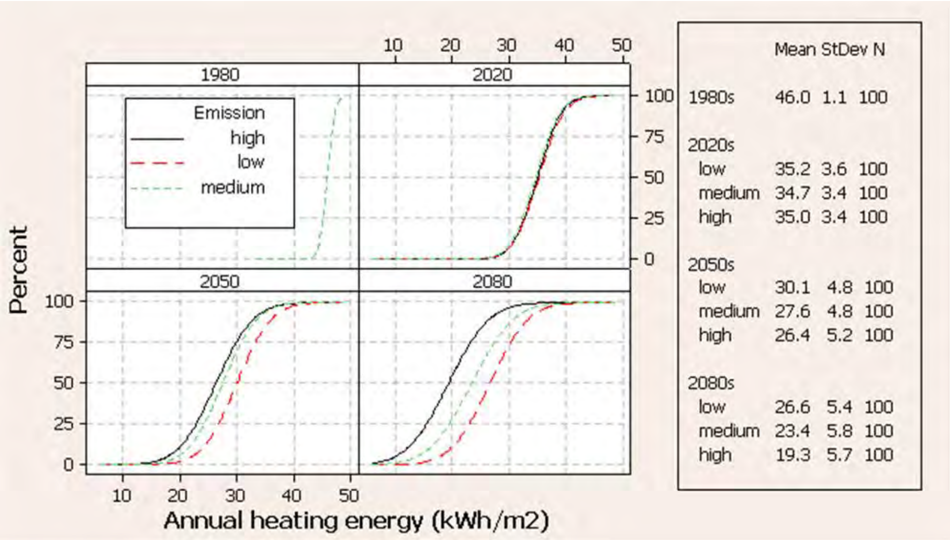
The simulation studies for the Roland Levinsky Building employ the recently released UK climate change predictions from UKCP09 (Murphy et al., 2009), which provides probabilistic climate change projections by means of a weather generator. For a given time period and emission scenario, the UKCP09 weather generator will generate 100 time series, each of which includes a 30-year hourly output for baseline and specified future time slice. Finkelstein–Schafer statistic is used to create one typical weather file from every time series of 30 years in length. This yields 100 typical weather files for a specified time slice and emission scenario. In order to analyse current and future thermal behaviour a series of time horizons and scenarios must be explored; at present this is still computationally expensive and requires 1000 EnergyPlus runs. This would take about 23 days on a regular office PC; hence use has been made of the local computing grid, allowing to run the same computations on different machines in parallel and reducing the computation time to just one weekend, see Figure 5.



User	Total Allocation Time (Hours)	JobsRunning Average	JobsIdle Average	JobsRunning Peak	JobsIdle Peak
Total	534.9	63.2 (83.9%)	17.1 (16.1%)	152.0 (100.0%)	102.0 (100.0%)
wtian UOPNET.plymouth.ac.uk	534.9	63.2 (83.9%)	17.1 (16.1%)	152.0 (100.0%)	102.0 (100.0%)

Figure 5: University of Plymouth Plymgrid usage statistics.

Initial results are just becoming available. These have been combined to plot cumulative distribution functions for annual heating energy, annual cooling energy and carbon emissions for the baseline period of 1961-1990 and future time horizons for the 2020s, 2050s and 2080s. See figure 6. Simulation results show that, by the 2050s, the mean annual cooling energy will have increased by 135% while the mean annual heating energy will have decreased by 40% relative to the current situation. The annual greenhouse gas emission will increase by about 20%. Work is currently starting to calibrate these initial results with data from the Building Energy Management System.



	Mean	StDev	N
1980s	46.0	1.1	100
2020s			
low	35.2	3.6	100
medium	34.7	3.4	100
high	35.0	3.4	100
2050s			
low	30.1	4.8	100
medium	27.6	4.8	100
high	26.4	5.2	100
2080s			
low	26.6	5.4	100
medium	23.4	5.8	100
high	19.3	5.7	100

Figure 6: Initial predicted heating energy use for the Roland Levinsky Building.

Overall, the building performance simulation studies (on both the TM36 O2 Reference office and the Roland Levinsky Building) lead to the following findings:

- It is possible to predict future thermal performance of buildings, taking into account a range of uncertainties, using (probabilistic) simulation.
- If so desired one can distinguish between aleatory uncertainty and epistemic uncertainty. However, in the context of actual projects the boundaries between these two become fluid.
- The usefulness of simulation results depends critically on modelling assumptions. For instance, choices made regarding thermal comfort (static or adaptive model) can have an impact of up to a factor three on predicted energy use.
- The new climate predictions of UKCP09 can be used in building simulation, but are computationally expensive. Strangly, UKCP09 does not contain predictions regarding wind, with the report mentioning that these would have too large an uncertainty range. This might be relatively unimportant for some buildings, but can be a crucial factor for naturally ventilated buildings, or buildings where convective heat exchange is dominant (eg. U-value of glazing).
- There are limits to what can be learned from studying a theoretical reference office like TM36 O2, as this does not allow the essential feedback of building stakeholders to computational results, and does not include an operational facilities management context. At the same time, studying actual buildings brings in so much additional detail that selection of what is considered to relevant and what can be simplified turns dominant.

4. Expert panel workshops

Results from the building simulation studies have been discussed with colleagues from practice and academia by means of a series of expert panel workshops. In these workshops the simulation research was presented, and feedback solicited from the workshop participants. Three workshops have been held thus far:

WS1: Invited lecture at Georgia Institute of Technology, College of Architecture, in the local Building Technology Seminar Series (Atlanta, USA, 30/10/2009; 20 participants)

WS2: Local workshop at Plymouth University, Environmental Building Group (Plymouth, UK, 26/11/2009; 10 participants).

WS3: IBPSA-England Worskhop at the Bartlett, University College London (London, UK, 08/12/2009; 25 participants).

The workshops have yielded the important feedback on the research, which is centred on two areas: refining the simulation and examining the 'soft' factors, with a purpose to improve future design and FM decision practice in response to climate change.

4.1 Refining the simulation

A number of comments were obtained regarding refining the simulation. Firstly, simple, pre-defined building intervention scenarios are not realistic. In real facilities management, the performance of a system will deteriorate, until a point is reached where the decision is made to replace that system. To represent this in the simulation, a coupling between predicted performance and interventions is needed. Secondly, even a building is designed without any climate change concerns being included in the client's brief, the CIBSE Design Guide might still provide a set of background requirements that any building in the UK will have to meet. Thirdly, although the study of the Roland Levinsky Building is interesting, a careful approach is needed to validate probabilistic simulation results against actual meter readings, for instance, from the Building Energy Management Systems (BEMS).

4.2 Examining 'soft' factors

Several 'soft' factors were also identified, which, although appearing difficult to be modelled in the simulation for the moment, were considered important to design and FM decision practice in relation to climate change. Firstly, the simulation engaged in this research was based on the use of gas-fired boilers as the base case, whilst it should not be unusual to expect a shift in technology over the lifetime of the building. For instance, the current gas-fired boiler might be replaced by a ground-source heat pump system, which might actually be likely to happen given the increasing take-up of alternative heating and cooling technologies for buildings in the UK, e.g. ground source heat pumps (Omer, 2008) and air source heat pumps (Jenkins et al., 2008). Also, it appears that electricity-driven technologies will increasingly be preferred to gas options in buildings, given the trend of decreasing carbon intensity of the grid. Therefore, potential technology development and diffusion in building seems to impose an uncertainty on the modelling approach. Secondly, the functional adaptability of the building, i.e. potential use changes during its life time, was not considered in the simulation. Also, the client's desire on and maintenance strategy for the building were not considered. From an estates point of view, building management is asset management, and is related to reserving funds for maintenance and interventions. This type of research, which explores when to intervene, seems very informative for that type of decisions. Thirdly, an extension of 'operating energy' to 'relative work performance' is relevant when taking a monetary view of decisions. An apparently small reduction in work performance of about 3% can equal the total cost of energy use per year when translated into investments.

4.3 Recommendations

Amalgamating the comments/feedback on the two areas suggests a balanced strategy for managing climate change risk for future buildings in relation to design and FM decision-making. On the one hand, attempting to consider too many uncertainties on the input side would yield simulation results that provide less useful information. On the other hand, the important 'soft' factors should be taken into account, with the simulation results, for enabling more effective design and FM decision practice (Figure 7).

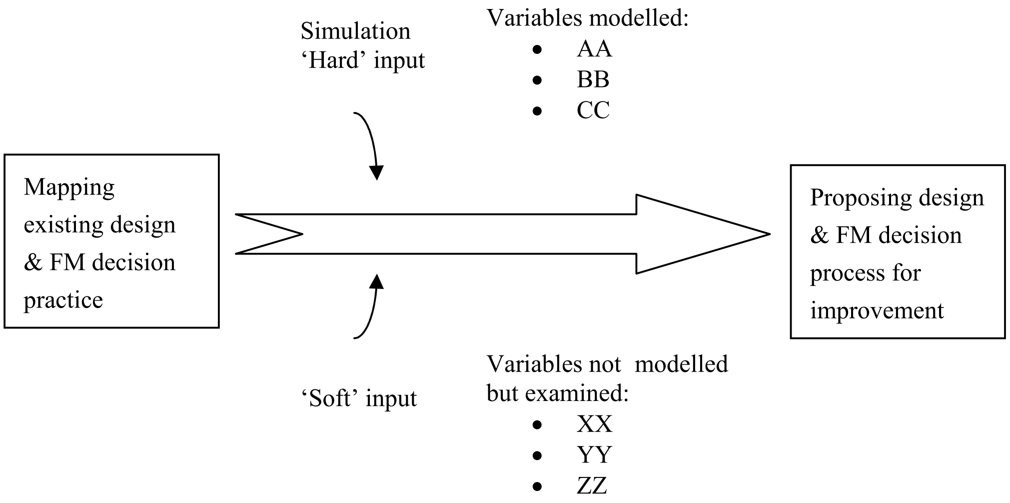


Figure 7: Model of climate change risk management for building design & FM decision

Both the simulation results and considerations for the 'soft' factors should be taken into account by the client and their professional advisers and FM managers for managing the climate change risk of the building. Recommendations to be made drawing on both 'hard' and 'soft' inputs would enable the development of improved design and FM decision processes. Apparently, a range of building stakeholders including the client, their professional advisers, FM managers, occupants and the public would need to be engaged. The management of climate change risk of the building would also need to involve a continuous review of the statutory, regulatory and technological context of building design and management.

5. Conclusions and remarks

This paper, reporting on a combination of the building performance simulation studies and expert panel workshops, has demonstrated that simulation can play an important role in managing buildings that are subject to a changing climate. However, computational studies need to be grounded in a real-life context to be of use. The development of relevant models needs to involve the stakeholders to ensure sufficient resolution on relevant details, covering non-trivial issues like uncertainties in renovation/intervention activities, changing heat load and user profiles, thermal comfort control assumptions, and system degradation. A general probabilistic approach will just yield that many input uncertainties lead to an uncertain future performance. The way forward in this field of research is a series of case studies that focus on actual buildings, which allows to consult stakeholders and to frame the relevant facilities management decisions in their real-life context, which can include non-thermal ('soft') factors.

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