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Climate Change Simulation for Intelligent Green Building Adaptation Design

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***Abstract*—A climate change simulation framework for intelligent green building adaptation design is proposed. The simulation framework is developed for studying environmental performance of existing or proposed green buildings under present and future urban microclimate conditions. It draws on a synthesis of environmental computer simulation in three areas: (1) overall climate change scenario modelling at city level, (2) outdoor urban microclimate modelling at neighbourhood level, and (3) indoor environmental simulation at building level. A case study of applying the climate change simulation framework to an existing university campus green building is presented for 2012 and 2050. In response to the simulation results, strategies for adapting the case study green building in relation to its changing urban neighbourhood are assessed as an example. The case study shows that the simulation framework can generate requirements for intelligent green building adaptation design by linking urban microclimate change projection to simulated energy demand in maintaining building indoor thermal comfort.**

Keywords - urban microclimate simulation; intelligent green building; climate change adaptation design; building energy simulation; thermal comfort

I. INTRODUCTION

According to the latest assessment report (AR5) published by the United Nation Intergovernmental Panel on Climate Change IPCC, with 95% certainty humans are the dominant cause of global warming since the 1950s [1]. The AR5 states that the global surface temperature increase by the end of the 21st century is likely to exceed 1.5°C relative to the 1850-1900 period, and is likely to exceed 2.0°C for many CO_2 emission scenarios. On 10 May 2013, the CO_2 levels in the atmosphere have broken through 400ppm (as measured at a US government agency lab on top of the Mauna Loa Volcano in Hawaii), which has not been seen since three to five million years ago on a regular basis [2]. Global warming caused by continuing increases of CO_2 emissions worldwide affects urban microclimate which in turn affects urban neighbourhoods and the buildings within. Urban dwelling in hot-arid and hot-humid regions is particularly sensitive to impacts of climate change as residents have a greater need to inhabit in between outdoor and indoor spaces. Therefore there is an urgent need to to assess how existing buildings or proposed building designs perform under changing urban neighbourhood context and microclimate conditions. This paper reports our development of a climate change simulation framework for intelligent green building adaptation design, focusing on the energy requirement for green building technologies in delivering thermal comfort under changing urban neighbourhood and urban microclimate. We expect that intelligent green buildings have an important role in developing green urban neighbourhoods resilient to climate change while minimizing carbon emissions. Our climate change simulation framework implements a novel workflow combining urban microclimate modelling, future climate change scenario projection, and building indoor energy simulation (section III). By applying the simulation framework to an existing campus office building at the University of Sheffield as an example, we show how the simulation informs intelligent green building adaptation design taking into account changing urban context and its microclimate (section IV).

II. RELATED WORKS

Kua and Lee argued that existing buildings should be given longer lifespan via uses of intelligent green technologies while future buildings should be designed and constructed with conservation in mind [3]. More recently Wilde and Coley pointed out the fast-moving field of research on the adaptation and resilience of buildings to a changing climate and its importance to the building industry [4]. Focusing on England's suburbs, Williams and co-workers have identified a number of potential adaptation options to reduce the climate risk within the context of local adaptive capacity [5].

III. A CLIMATE CHANGE SIMULATION FRAMEWORK

Figure 1 presents a proposed climate change simulation framework that aims to assess and inform intelligent green urban neighbourhood and building design taking into account current projection of climate change scenarios published by climatological research programs such as the UKCP09 [6].

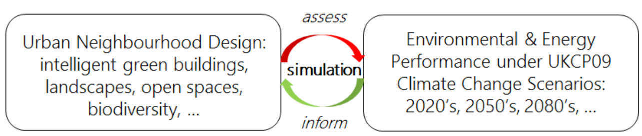

Figure 1. A proposed climate change simulation framework for assessing and informing green urban neighbourhood and building design

Broadly speaking, urban neighbourhood design covers specification of 3D form and materials for the construction of buildings, landscapes, and other utilities to be inhabited by people as well as wild lives (biodiversity) over a planned period of time. As a spatial scale, a number of urban neighbourhoods joining together may form significant parts of a city, while zooming into a single neighbourhood, we see a cluster or individual buildings. We therefore expect that intelligent green buildings will play an important role in achieving climate change resilient green urban neighbourhoods and cities while minimizing carbon emissions. Figure 2 presents our current implementation of the climate change simulation framework using a number of software tools including ENVI-met, CCWeatherGen and DesignBuilder.

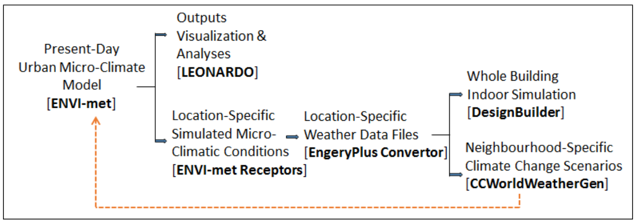

Figure 2. A workflow implementing the climate change simulation framework using ENVI-met, LEONARDO, EnergyPlus Convertor, DesignBuilder and CCWorldWeatherGen

Developed by Michael Bruse and team at the University of Mainz, ENVI-met is one of the first computational models to simulate air-plant-surface interaction affecting urban microclimates based on computational fluid dynamics and thermodynamics [7]. The latest release ENVI-met (version 3.1 Beta 5), including LEONARDO for visualization of simulation output, has been extended to model an even wider range of thermal interactions of the built environments. Using the 2002 climate change scenario projections provided by the UK Climate Impacts Programme, CCWeatherGen generates climate change weather files for the UK ready for use in building performance simulation programs [8]. Based on the EnergyPlus whole building energy simulation engine developed by the Laurence Berkeley Lab, DesignBuilder (version V2.3.5.36 used in this study) provides proprietary graphical user interfaces for rapid simulation of building indoor environments. The underlying principle of our workflow design above centers on outdoor-indoor coupled environmental modelling and simulation, which is open to alternative software tools if identified in future studies.

IV. THE ICOSS BUILDING STUDY

To test the above climate change simulation framework and workflow, we have conducted a case study of a green building on the Sheffield University campus. Designed and engineered as a naturally cross-ventilated office building without an air-conditioning system, the Interdisciplinary Centre of the Social Sciences (ICoSS) has a south-facing atrium creating a thermal stack with supply of replacement air via openings on the north façade (Figure 3.a-c). The fully-glazed south façade is equipped with a series of automated roller blinds to moderate solar gains for different weather conditions and internal patterns of use. In addition, night time cooling is operated by a Building Management System (BEMS). In the following subsections, we present our ICoSS neighbourhood outdoor and building indoor coupled climate change simulations in five steps: (A) ENVI-met microclimate modelling of the neighbourhood for 24 July 2012 as the hottest day of the year; (B) ENVI-met modelling of the neighbourhood for 24 July 2050 taking into account the changing urban neighbourhood (from Figure 3.c to 3.d) and CCWeatherGen projection of 2050 climate change scenario; (C) DesignBuilder simulation of the ICoSS building indoor environment for 24 July 2012 with the weather data generated from the microclimate modelling in (A); (D) DesignBuilder simulation of the ICoSS building for 24 July 2050 with the weather data generated from the ENVI-met microclimate modelling in (B); and (E) DesignBuilder simulations of three different shading strategies and the estimated energy requirements for maintaining summer thermal comfort level in summer 2012 and 2050.

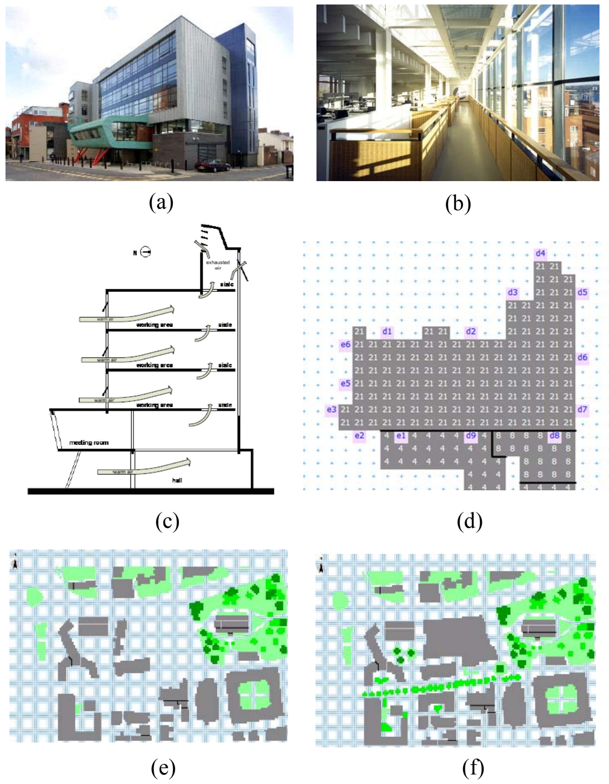

Figure 3. ICoSS building study: (a) exterior north-facing entrance view, (b) interior south-facing façade view, (c) section showing the natural ventilation scheme, (d) locations of 15 ENVI-met receptors for the ICoSS outdoor-indoor coupled simulation, (e) input area for ENVI-met urban microclimate modelling 2012, (f) input area for ENVI-met modelling 2050

A. *ICoSS Urban Neighbourhood Outdoor Microclimate Condition: 2012*

Figure 4 shows visualization of ENVI-met modelling of the present ICoSS campus neighbourhood (24 July 2012, 15:00, representing the hottest day and hour of the year).

B. *ICoSS Urban Neighbourhood Outdoor Microclimate Condition: 2050*

Figure 5 presents visualization of ENVI-met modelling of future ICoSS neighbourhood (24 July 2050, 15:00, as the assumed hottest day and hour of the year). Here, not only the climate change scenario projected by CCWeatherGen but also the substantial changes in the neighbourhood itself are taken into account, notably the construction of the New Engineering Building and associated outdoor landscaping and plantation. Visual comparison suggests that the overall change in air temperatures around the ICoSS building is not dramatic (see row (B) and row (D) in TABLE I), however the changes in wind direction and speed is significant which may have some impact on the performance of the natural ventilation system.

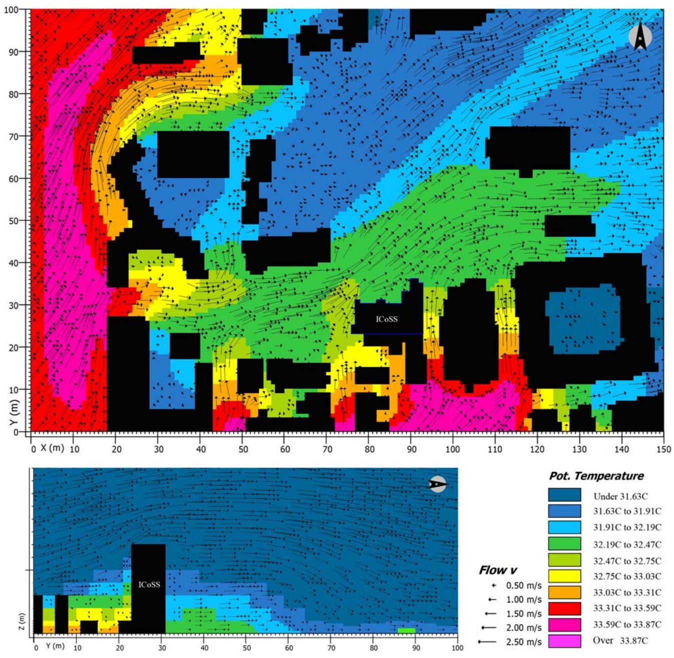

Figure 4. ENVI-met simulation of the ICoSS neighbouthood, 24 July 2012, 15:00, showing Potential Air Temperature, Wind Direction and Wind Speed

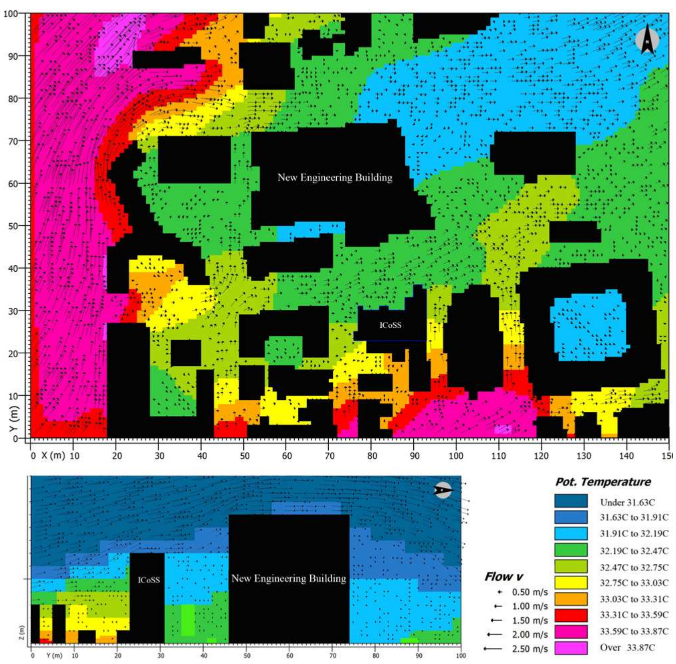

Figure 5. ENVI-met simulation of the ICoSS neighbouthood, 24 July 2050, 15:00, showing Potential Air Temperature, Wind Direction and Wind Speed

TABLE I. ICOSS NEIGHBOURHOOD OUTDOOR AVERAGE HOURLY AIR TEPERATURES [°C, 24 JULY AS THE HOTTEST DAY OF THE YEAR]: (A) REMOTE WEATHER SATION 2012, (B) ENVI-MET SIMULATED 2012, (C) REMOTE CCWEATHERGEN 2050 SCENARIO, (D) ENVI-MET SIMULATED 2050

	$8^{:00}$	$9^{:00}$	$10^{:00}$	$11^{:00}$	$12^{:00}$	$13^{:00}$	$14^{:00}$	$15^{:00}$	$16^{:00}$	$17^{:00}$	$18^{:00}$
(A)	22.1	23.1	24.2	25.4	24.6	25.0	27.3	27.2	27.0	26.9	26.7
(B)	24.7	25.9	26.9	28.4	30.0	31.4	32.1	32.1	31.7	31.0	29.7
(C)	23.8	24.8	25.9	27.1	26.3	26.7	29.0	28.9	28.7	28.6	28.4
(D)	26.0	27.1	28.0	29.1	30.5	31.7	32.2	32.4	32.2	31.6	30.6

C. ICoSS Building Indoor Thermal Comfort Condition: 2012

Figure 6 shows visualization of DesignBuilder simulation of the present ICoSS building's indoor environmental conditions (24 July 2012, 15:00). Note that as a green building no HVAC-based cooling is provided in ICoSS, and the building is clearly predicted significant overheating with its existing natural ventilation system on this summer day/hour. The simulation outcome confirms an earlier study of the ICoSS building during 2006-08, which reports a series of overheating problems in late spring and summer periods [9].

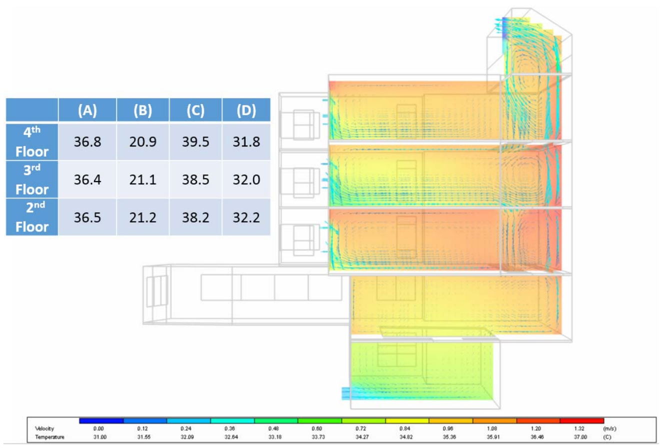

Figure 6. ICoSS ENVI-met and DesignBuilder coupled simulation for 24 July 2012, 15:00: (A) Air Temperature [°C], (B) Relative Humidity [%], (C) Mean Radiant Temperature [°C], (D) Outdoor Air Temperature [° C].

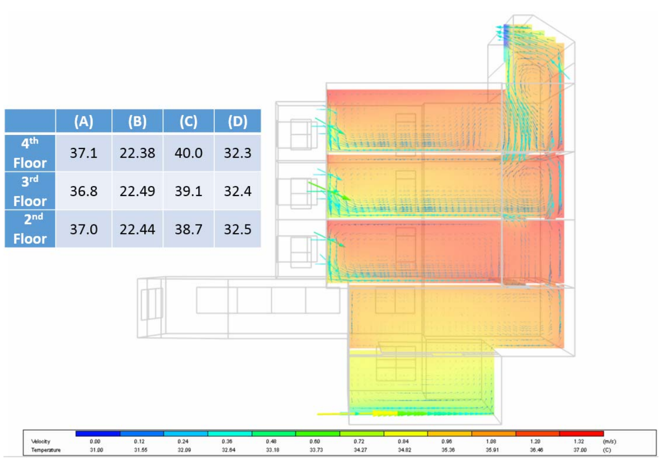

Figure 7. ICoSS ENVI-met and DesignBuilder coupled simulation for 24 July 2050, 15:00: (A) Air Temperature [°C], (B) Relative Humidity [%], (C) Mean Radiant Temperature [°C], (D) Outdoor Air Temperature [° C].

D. *ICoSS Building Indoor Thermal Comfort Condition: 2050*

Figure 7 shows visualization of DesignBuilder simulation of future ICoSS building's indoor environmental conditions (24 July 2050, 15:00). Both the predicted air temperatures and mean radian temperatures (MRT) increase. Given that all other sources of internal heat gains such as lighting, equipment uses, and occupancy level are the same, the increase in the predicted MRT of 2050 is noticeable even with predicted decrease of the solar gains in 2050 (row 2012A and row 2050A in TABLE II).

TABLE II. INTERNAL HEAT GAINS [24 JULY 2012 AND 2050]: (2012A) SOLAR GAINS [KW], (2012B) % OF SOLARGAINS OVER TOTAL HEAT GAINS; (2050A) SOLAR GAINS; (2050B) % OF SOLARGAINS OVER TOAL HEAT GAINS

	8^{00}	9^{00}	10^{00}	11^{00}	12^{00}	13^{00}	14^{00}	15^{00}	16^{00}	17^{00}	18^{00}
2012A	13.9	20.8	30.7	44.9	63.8	55.4	46.7	35.5	22.7	12.3	8.4
2012B	25.3	32.6	42.2	52.2	61.9	59.1	55.1	48.4	37.5	25.1	18.6
2050A	13.0	19.9	30.2	46.5	62.5	52.7	39.4	26.5	15.7	8.1	6.6
2050B	24.4	31.6	41.8	53.0	61.4	57.9	50.9	41.1	29.3	18.0	15.1

E. *Adapting ICoSS for Climate Change: The Energy Requirement for Green Building Adaptation Design*

The previous four stages of coupled urban neighbourhood microclimate modelling and building indoor simulation have shown the extent of summer overheating in ICoSS both for 2012 and 2050. The objective is to overcome the overheating problem while maintaining ICoSS as an intelligent green building. Our final stage of the simulation study is to explore additional passive design futures: interior or exterior shading devices (Figure 8). An external louver system for the south-facing façade is also proposed (Figure 9).

(A) (B)

Figure 8. ICoSS south-facing façade shading schemes: (A) No shading is provided; (B) internal roller blinds applied

In DesignBuilder, the thermal comfort calculation is based on ASHRAE 55-2004 [10]: air temperature 24°C, relative humidity 50%, and MRT 31°C. To achieve this thermal comfort standard, we further estimate the chiller capacities required under the different shading options (TABLE III). The percentages here indicate the ratios of chiller required to the estimated overall energy demand of the building floors. Clearly, scheme C (i.e. fitting the external louver system on the south-facing façade) is predicted to outperform the others. However, our current simulation shows that for the ICoSS building to deliver optimal thermal comfort for present time and 2050, it requires extra energy to mitigate the excessive summer heat even if an external louver system is fitted on top of its existing natural ventilation. Therefore, the challenge for further adaptive green building technologies is how to attain the amount of chiller-running energy required while minimizing carbon emissions.

	2012A	2050A	2012B	2050B	2012C	2050C
4th Floor	36.8	37.1	36.8	37.0	35.3	35.7
3rd Floor	36.5	36.8	36.4	36.5	35.0	35.4
2nd Floor	36.8	37.0	36.5	36.6	34.9	35.4

2012A: no shading year 2012
2050A: no shading year 2050
2012B: internal roller screen year 2012
2050B: internal roller screen year 2050
2012C: external louver year 2012
2050C: external louver year 2050

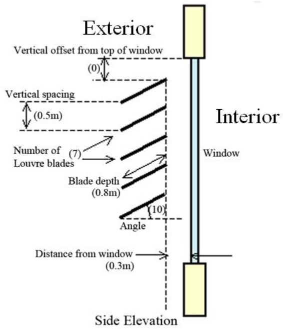

Figure 9. Comparison of indoor air temperatures [°C] under three different shading adaptation designs on the south façade

TABLE III. ENERGY DEMAND FOR COOLING UNDER THREE SHADING ADAPTATION DESIGNS (ALL FOR 24 JULY, 15:00)

	2012A	2050A	2012B	2050B	2012C	2050C
Chiller kW (%)	595.98 (53.6%)	614.14 (54.4%)	598.17 (53.4%)	623.16 (54.4%)	479.77 (49.3%)	493.51 (50.0%)

V. CONCLUSION AND FUTHER RESEARCH

A climate change simulation framework and workflow for assessing and informing intelligent green building adaptation design is proposed. Applying the simulation workflow to an existing green building as an example of adaptation design, we show how the energy requirement is modelled and specified for green building technologies to mitigate summer overheating while minimizing carbon emissions. To attain fuller energy requirement profiling for intelligent green building adaptation design, further simulation study into other seasonal conditions is required. This will inform potential links with smart grid development to implement new capabilities of modelling intelligent green urban neighbourhoods and smart cities.

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