INTENSIVE BUILDING ENERGY SIMULATION AT EARLY DESIGN STAGE

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ABSTRACT

In order to inform the design of a building or a group of buildings in relation to their potential energy efficiency, the main impact will be at the initial concept design stage. Variations and interactions of parameters need to be considered quickly as the design develops. In addition to the variation and interrelation of parameters associated with individual buildings, the design should consider the influence, both from and on, neighbouring buildings and landscape features. This paper describes the development of two modelling processes, based around the established building energy model, HTB2, and the urban scale energy model EEP. Example case studies from China are given to illustrate the processes.

INTRODUCTION

Computer simulation is now commonly used to predict the energy performance of buildings. It can range from relatively simple annual energy predictions, such as used in conjunction with building regulations, for example, UK SAP (DECC, 2012), to more advanced numerical models that predict the detailed energy and thermal performance, typically on an hourly time scale over a year, such as Energy + , ESP-r, TRNSYS, and HTB2. HTB2, developed at the Welsh School of Architecture, Cardiff University, is typical of the more advanced numerical models, using as input data, hourly climate for the location, building materials and construction, spatial attributes, system and occupancy profiles, to calculate the energy required to maintain specified internal thermal conditions (P.T. Lewis, D.K. Alexander, 1990). HTB2 has advantages of flexibility and ease of modification, which makes it well suited for use in the field of energy efficiency and sustainable design of buildings, which is rapidly evolving. It has been developed over a period of over thirty years and has undergone extensive testing, validation, including the IEA Annex 1 (Oscar Faber and Partners, 1980), IEA task 12 (Lomas 1994) and the IEA BESTEST (J. Neymark et al, 2011).

Computer simulation of new buildings should inform the design process. It will therefore have best impact if performed at an early design stage. At this stage there are generally many unknowns, and so early stage simulation will need to include default values, and needs to be carried out as simply as possible. There may be a number of iterations in order to optimise energy performance as the design develops. It is generally more common to carry out simulation on a relatively completed building as a check on its performance, maybe related to an environmental assessment process such as LEED or BREAM. However, in such cases, at this relatively late stage, there may be little scope to make major adjustments to the design. It is therefore important to differentiate between 'early stage' simulation that is carried out to inform the design process, and that which is carried out to check the final design.

At an early stage of design, it is often necessary to examine a range of options quickly. Projects may involve more than a single building, or may need to consider a building within the context of its surroundings, and at urban scale. Even though this is carried out at an early design stage, both can involve intense computing, either many options for one building, or many buildings simultaneously.

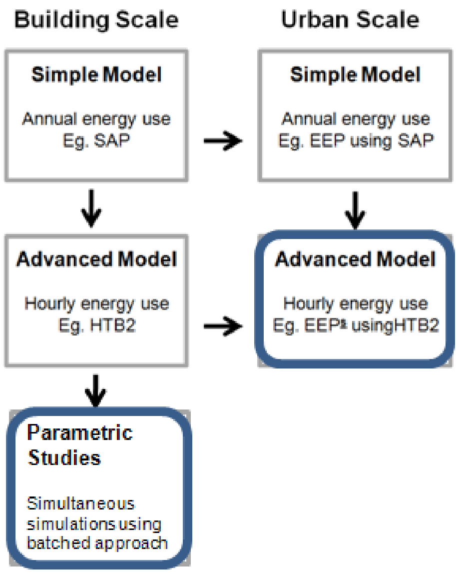

Figure one Development of building energy simulation highlighting the two developments in this paper

Figure 1 illustrates how building energy simulation has developed from simple modelling to more advanced modelling, and how advanced models are now being applied at urban scale. It also illustrates how advanced models can now be used to carry out parametric studies of 1000's of annual hourly simulations simultaneously. Such developments incur large data sets in both the setting up of simulations and analysis of results, which places greater stress on pre-and post-processing.

This paper describes the development of HTB2 within this intensive computational framework, focussing on two processes. The first process involves the modelling of multi-building scale developments, typically up to a few hundred buildings, which could be a new or existing development, or a mix. The second process involves the consideration of multi-parameter options for an individual building type. A range of parameter variations can be selected for a specific building type, typically including variations in, facade u-values, glazing ratio's, glazing g-values, HVAC systems, ventilation and internal gains. These are all run within HTB2 as a batch process. The results are interrogated using an on-screen 'sensitivity tool' to quickly evaluate the annual and seasonal heating and cooling energy performance. Where appropriate, the two processes may be combined for a specific project to quickly determine the most appropriate design for efficient energy use and reducing carbon dioxide emissions.

To illustrate the use of the two processes, example case studies are referred to in the proceeding sections, based on work carried out in Chongqing, China.

URBAN SCALE MODELLING

Large 'urban-scale' energy simulation is a field that has not been approached as widely as energy simulation for individual building design. Issues of detailed modelling at an urban-scale have in the past been too computer intensive. Earlier models, such as the Energy and Environmental Prediction (EEP) model (P. Jones, et al, 2007), used relatively simple annual energy modelling, namely the UK SAP tool (DECC, 2012). In addition, EEP was mainly developed to consider the energy performance of the existing built environment rather than new developments, being initially developed to assess energy performance, to identify the highest energy users, and to determine the most cost effective package of energy saving measures for specific groups of building types (Fragaki A, et al, 2008). However, today's access to high levels of computer power can facilitate the modelling of large numbers of buildings at the same time, using advanced simulation models, such as HTB2. Other examples have focussed on solar radiation and occupancy behaviour (Robinson D, et al, 2007, 2009)

Buildings in the context of its surroundings

Urban scale modelling has wider implications compared to modelling individual buildings. Firstly, it might consider the interaction of buildings, such as overshadowing in relation to solar energy incident on the building, and any associated solar collection strategies. It might consider the microclimate developed at the urban scale, for example, the mix of green areas and buildings, and transportation systems, in relation to the urban heat island effect. This may be used to assess the most appropriate density of development. There will be conflicting strategies, such as potential loss of daylight and reducing cooling demand from increased densities.

Buildings are not independent of their surroundings in relation to their energy performance. They may be overshadowed by other buildings or landscape features, there may be reflected radiation from adjacent surfaces, and there may be microclimate effects through urban heat islands and breezeways. There may also be effects from adjacent infrastructures and transport systems. So, the performance of a building is affected by its surroundings. In turn, a building will affect its surroundings contributing to the microclimate, which in turn affects its own, and other buildings performance. Any relationship to external surroundings, for example, overshadowing of neighbouring buildings, is usually relatively simple when carried out at an individual building scale, but increases in complexity with more buildings and the presence of other landscape and natural features.

The approach here uses Trimble SketchUp to construct the building development and to provide information on the shading of buildings by each other. The data is then supplied to the energy model, and the simulation is run from within SketchUp and the results displayed. The approach aims to provide results for operational energy use, embodied energy and the potential for solar energy for building integrated renewable energy systems. Individual building performance can be identified alongside whole site performance.

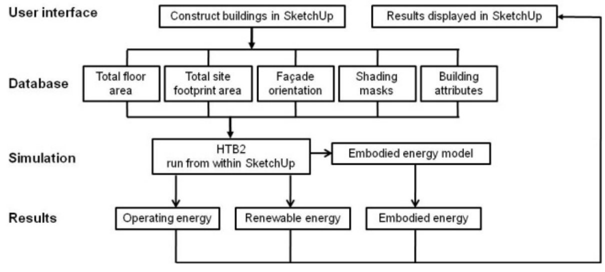

Figure 2 Structure urban modelling framework

Figure 2 outlines the different stages of the EEPs process. A range of 'plugins' have been developed in order to extract information from a simple SketchUp model, generating information on each building and making each building 'aware' of its surroundings. The data is transferred from SketchUp to HTB2, which is then run from within the SketchUp environment. The results are produced and displayed within SketchUp.

The framework developed around SketchUp, in addition to generating the geometric information, has to be supplied with the meteorological data, construction data, services and occupancy patterns, which can also be input through the SketchUp plugins.

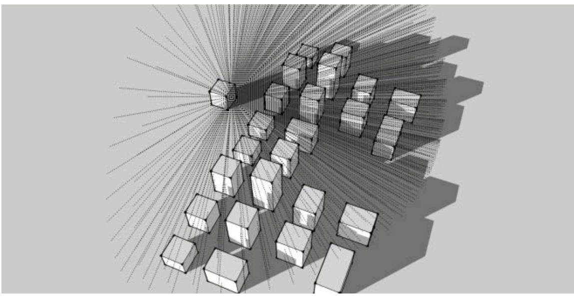

Figure 3 Surrounding awareness.

Overshadowing

While SketchUp is a useful sketching tool for the generic user, its embedded programming language provides better control to users over every object in the model (edge, face, arc, 3D points). Any object in SketchUp can be attributed, and these attributes can incur a unique ID, which thereafter provides descriptions of the objects, activating the ability to create an "attributes dictionary" and adding the capability of the model to be fully 'aware' of its surroundings (Figure 3). This allows sub-models to be developed that describe the interaction of buildings with each other, such as overshadowing. Using the plugin, each façade can fire out lines at set defined angular spaces (for example 1^o, 5^o, etc.) depending on the accuracy required. When each line meets an obstacle such as a building this is detected and the information is used to generate a shading mask for that façade. Figure 4 presents an example of the shading mask generated for a façade overshadowed by other buildings, topography or landscape features. It shows the sky-view hemisphere from which the shading mask in generated.

In many cases energy modelling assumes a level site with no consideration of geographic features. However, the location of the site can be chosen through the SketchUp framework allowing the user to import the topography of the site from Google Earth. The component behaviour attributes of SketchUp also applies to the imported topography, which allows for the analysis of buildings in deep valleys (figure 4(b)).

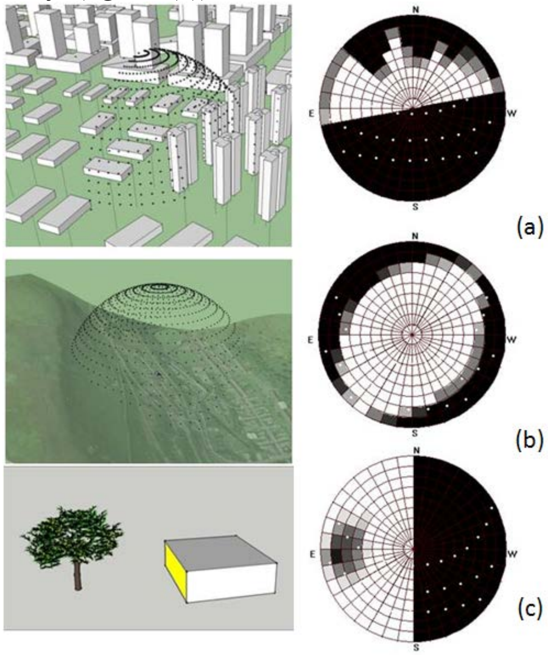

Figure 4 The shading effect on a facade with its resulting shading mask for (a) neighbouring buildings, (b) topography, (c) landscape features.

As links between Google Earth, Trimble 3D Warehouse, and SketchUp improve, more of our physical environment will be available to download for urban scale analysis. Currently a broad selection of existing buildings in our cities is available to download into SketchUp, and this choice will continue to increase over time.

Example application

An example from a low carbon master-plan study of about 300 buildings, including, residential, commercial and industrial, in Chongqing, China, is used to illustrate the energy analysis features of the process.

The HTB2 model predicts the solar radiation falling on each façade of a building, taking account of any overshadowing. If a solar collecting device is placed on a roof or façade, this can be modelled as an independent wall with appropriate angle and orientation and the incident solar radiation calculated in the same way as for building facades. The solar potential can then be viewed using the SketchUp plugin and visualised in SketchUp as a thematic map, as illustrated in figure 5. Results can then be used to provide the solar PV or solar thermal potential estimated using specific system efficiencies.

The energy performance of the whole development or individual buildings can be simulated and the results accessed through the SketchUp environment. Figure 6 presents output for individual buildings, located against the plan, and for the whole site, divided into elements of performance, including, heating load, cooling load, solar gain, etc.

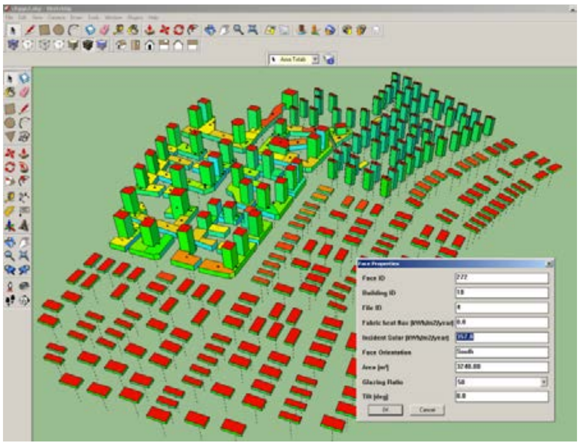

Figure 5 Solar radiation results displayed in SketchUp

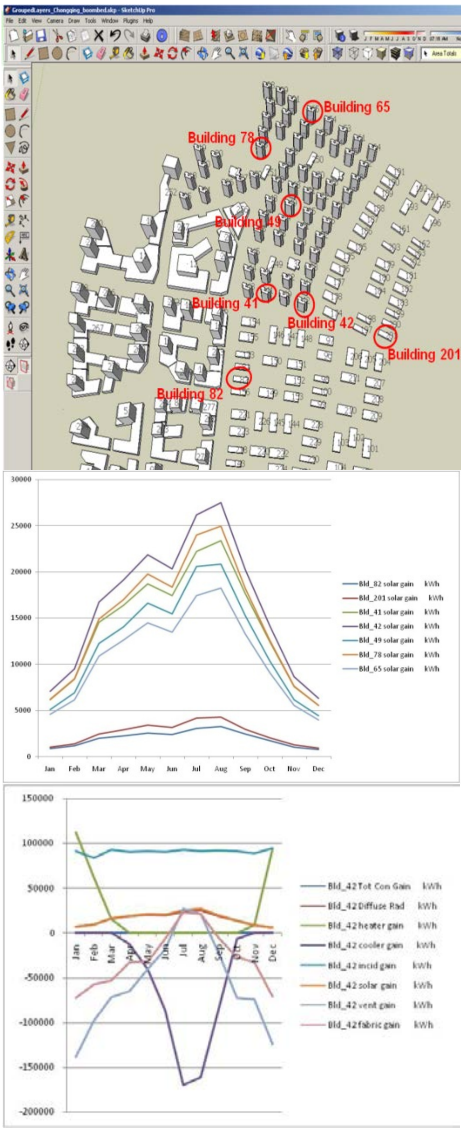

Figure 6 Energy analysis output for specific buildings and elements of energy performance for the whole development.

Figure 7 presents the overall results of the simulation, relating energy demand, energy supply and carbon dioxide emissions for the whole site, taking account of efficiencies and coefficients of performance for mechanical services and carbon dioxide emission factors for fuel type.

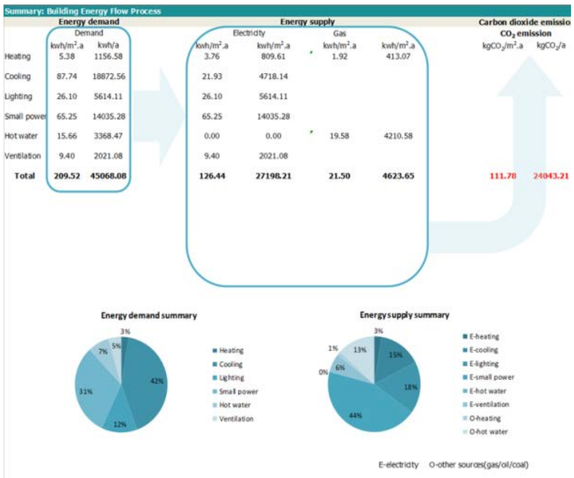

Figure 7 energy demand, supply and carbon dioxide emissions for the whole site

MULTI-PARAMETER SINGLE BUILDING MODELLING

HTB2 has been developed to carry out parametric analysis of building types as part of an early design stage modelling capability. In the case study presented here, over 4,000 hourly annual energy simulations were carried out, generating millions of data items. A post-processing ‘sensitivity tool’ is then used to easily interrogate the results.

Using the standard data for office building design in China, together with information on the office case study (provided by Chongqing Academy of Science and Technology, CAST), which was specific to Chongqing, a test model with a symmetrical layout and simple functional zoning (office surrounding central circulation and services zone) was constructed to represent the building for the purpose of early stage design simulation. At this stage, the detailed design of the building would not be realised. The triangular floor plans illustrated in the figure formed the basis for the simulations. The glazing ratio for each facade was set as 50%, and the floor height for standard floor was 3.6 meters. Simulations were carried out at space / room level (the blue area towards south) with variants including fabric U-value, window G-value, ventilation option, internal gain, orientations, to test the energy performance through different passive design strategies.

The indoor design conditions used for the simulations was taken from the design standards described in Design Standard for Energy Efficiency of Public Building GB 50189-2005, as well as the Design Standard for 50% Energy Efficiency of Public Building in Chongqing Area DBJ50-052-2006.

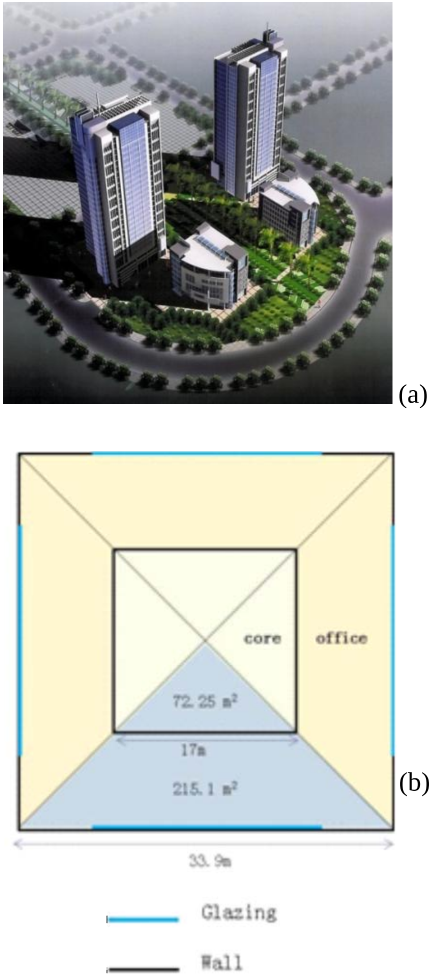

Figure 8 (a) Example building and (b) simplified form for initial sensitivity analysis.

The settings for the parameter variations are presented in table 1. The highlighted values are set for the standard case (the base case).

Figure 9 summarizes the simulation results for all 4608 runs, regarding the sensitivity of different variants in relation to their annual heating and cooling energy consumption. Overall, the heating energy varies between 0 and 35 kWh/m^2/annum, and the cooling energy from 29 to 125 kWh/m^2/annum. In each graphs, dots colour relates to the variant classification. The graphs indicates the following trends.

Table 1 Different variables and their values

VARIABLES IN RELATED TO PASSIVE DESIGN STRATEGIES	**VALUES**
External wall U-value (W/m²K)	0.3 - 0.7 - **1.1**
External window U-value (W/m²K)	1.0 - 1.5 - **2.5** - 3.5
External window G-value	0.1 - 0.2 - 0.4 - **0.6**
Ventilation (night air change rate for spring, autumn and summer)	0.5 - **2.0** - 6.0
Internal Heat gain (including lighting, equipment and occupants) (W/m²)	25 - 35 - 45 - 55
Orientation	S - SW - W - NW - N- NE -E - SE

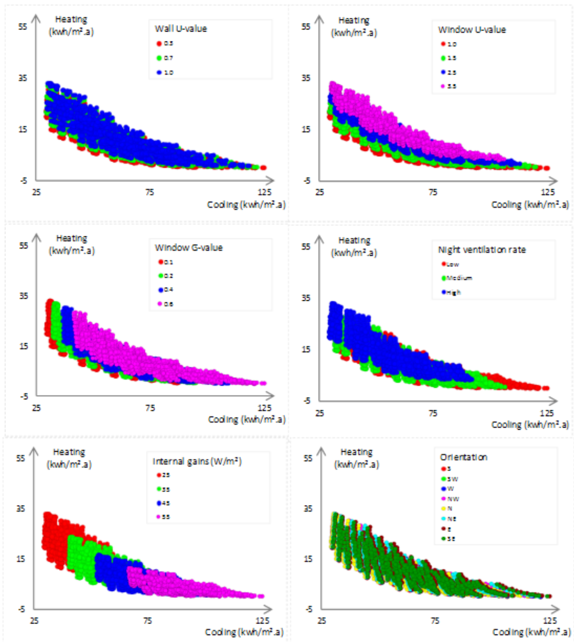

Figure 9 Sensitivity analysis for different variants in GIS (Top-left: wall U-value, top-right: window U-value, middle-left: window G-value, middle-right: night ventilation rate, bottom-left: internal gains, bottom-right: orientation)

- The cases with high wall U-value (blue dots) tend to use more heating energy, but this trend is not strong according to the majority overlapping of different dots, implying not much influence from external wall U-value.
- The cases with high window U-value (purple dots) use more heating energy, but less cooling energy. The trend is stronger than 5a, as there is less overlapping area in this graph, implying a greater impact from window U-value than that from external wall U-value.

- In general, cases with high window G-value (purple dots) use more cooling energy, but less heating energy. The trend is shown clear through the scatter of different colors with little overlapping area, implying great influence from window G-value.
- In general, cases with high night ventilation rate (blue dots) use more heating energy, but less cooling energy. The scatter of different colors shows an influence from night ventilation rate.
- In general, cases with high internal gains (purple dots) use more cooling energy, but less heating energy, vice versa. The trend is strong through the clear scatter of different colors, implying significant influence from internal gains.
- This orientation case shows no distinct trend, implying little impact from orientation. This is a response to the specific climate of Chongqing, which has a high instance of cloud cover.

Figure 10 summarises the impact of the variations, indicating that window g-value and the level of internal gains have the main impact for office design in Chongqing.

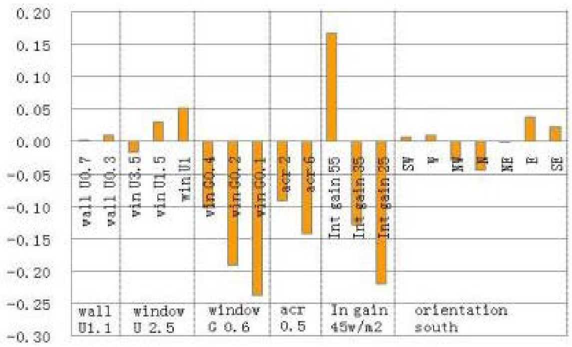

Figure 10 Variance ratios of annual energy consumption of single variant changes from base case.

The sensitivity tool

Based on the simulation results, a sensitivity tool was developed to aid decision-making for building design at an early stage. It can access the results from all 4608 annual simulations on a single computer screen. It describes the annual and monthly energy consumption for different combinations of variants by moving the buttons as required. Besides, by comparing the simulation results, the user can gain a better understanding about the sensitivity of different variants in relation to their impact on building energy performance, and identify the most effective design strategies afterwards. Figure 11 shows the sensitivity tool set up three cases, 'base case', 'best case' and 'best practical case'. The sensitivity tool allows the user to adjust the values of the variants and obtain data immediately for monthly energy use for heating, cooling, and annual energy use (heating, cooling and total).

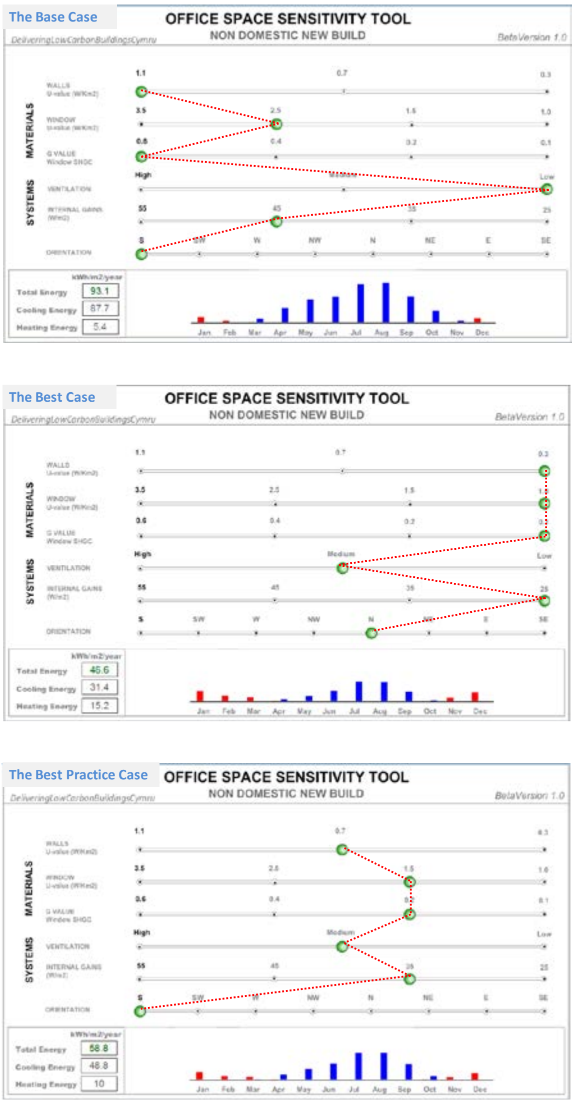

Figure 11 Sensitivity Tool set up for the base case (top), the best case (middle) and the best practice case (bottom).

The parameter values associated with the three cases are presented in table 2 and the total energy and percentage savings over the base case presented in table 3. The total energy savings from going from the base case to the best case are 50%. However, the best case was considered too costly and difficult at the current time. Therefore a compromise 'best practice' case was chosen (see values in table 2).

Table 2 Example of a table Best Practical Case

VARIANTS	STANDARD CASE	BEST CASE	BEST PRACTICAL CASE
Wall U-value	1.1 W/m²K	0.3 W/m²K	***0.7 W/m²K***
Window U-value	2.5 W/m²K	1.0 W/m²K	***1.5 W/m²K***
Window G-value	0.6	0.1	**0.2**
Ventilation	0.5 acr	2.0 acr	**2.0 ac**
Internal heat gain	45 w/m^2	25 w/m^2	***35*** $\boldsymbol{w/m^2}$

Table 3 Setting Targets energy performance for the base case, the best case and the best practical case

	ANNUAL ENERGY CONSUMPTION (KWH/M^2)	ENERGY SAVING RATE
Base case	93.1	0%
Best case	46.6	50%
Best practical case	58.8	36.8%

In order to target the level of energy savings appropriate to a specific situation, a range of levels of savings are summarised in table 4. The proposed level of savings suggested from this study fall between level 1 and 2, which is probably appropriate for the office design situation in Chongqing. The information in table 2 can therefore be used to inform the initial design process.

Table 4 Target reductions

STANDARD		ENERGY REDUCTIONS	DESCRIPTION
Level 1	Basic level of improvement	25%	***General improvements from regulations***
Level 2	Low carbon performance	50%	***Environmental assessment methods***
Level 3	Zero carbon performance	75%	***Passivhaus / towards zero carbon performance***

Sensitivity analysis for other Chinese locations

The results from the sensitivity analysis can be summarised in a plot as shown in the top left of figure 12, for Chongqing, indicating the impact importance of the different variants. This can be repeated for the same building but in different climate zones, as indicated in the five other plot in figure 12, corresponding to the locations in figure 13. This summary of impact of variants indicates that a different approach to low energy design should be adopted according to climate zone. For example, thermal insulation does not have a high impact in warmer zones, where the window g-value is of more importance.

CONCLUSIONS

This paper has presented two computational intensive energy simulation processes associated with early stage single building and urban development.

They illustrate how such simulations can assist in early stage design decision making providing a relatively speedy method of setting up and analysis large data sets associated with simulating many buildings simultaneously and many variants for a single building.

Further work is underway to develop urban scale modelling to include more details of microclimate, including local external temperature and breeze. Also the ‘sensitivity’ tool is being developed to contain more variants and to be operated through a tablet device, eg. Ipad.

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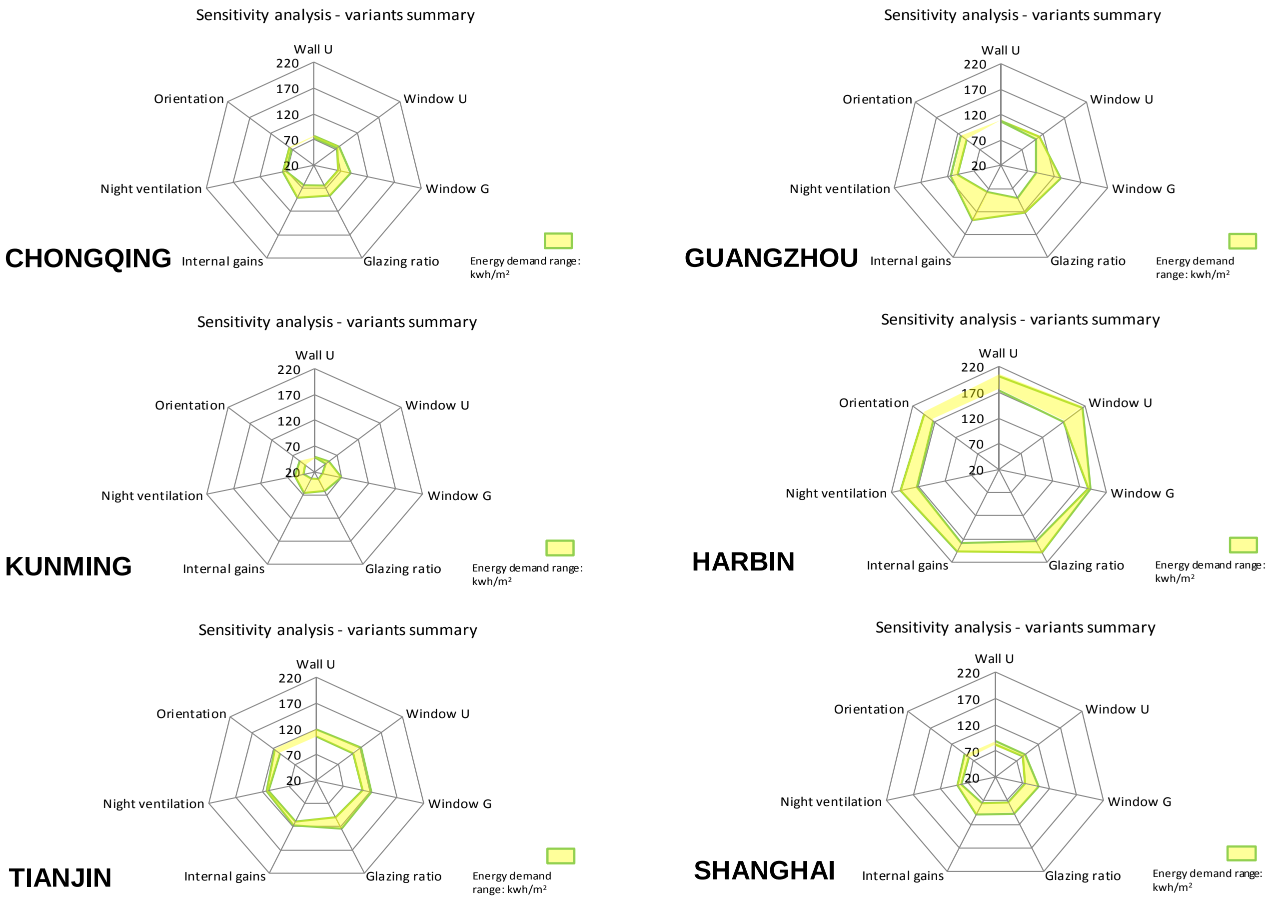

Figure 12 Analysis from 6 locations in china

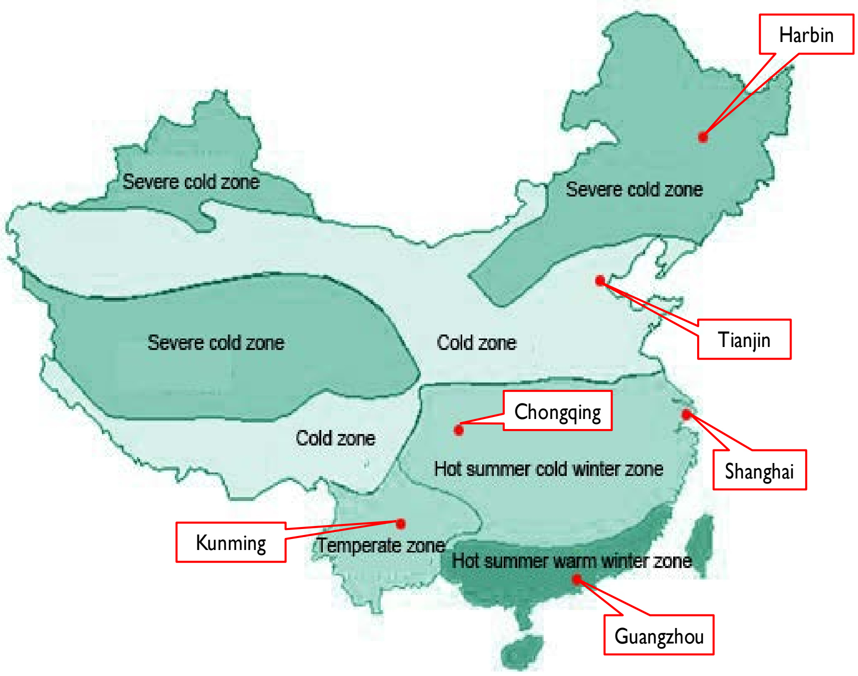

Figure 13 Locations of sensitivity analysis and climate zones in China.