A new approach to urban environmental modelling

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A thesis submitted for the degree of

Doctor of Philosophy (by Published Works)

22 April 2015

Contents

Acknowledgments

I would like to take the opportunity to thank the co-authors and contributors to the papers included in this thesis; Don Alexander, Tom Bassett, Mahmoud Elsayed, Aliki Georgakaki, Heledd Iorwerth, Qian Li, Xiaojun Li, Orly Linovski, Stuart Macdonald, Jo Patterson, Hendrik Rosenthall, Lu Sun and Diana Waldron.

Phil Jones has been both co-author and thesis supervisor, and provided the opportunity for this work to happen.

On a personal level I would like to thank Huw Jenkins for keeping me on the rails, Zbig Sobiesierski and Mike Fedeski for challenging me to explain it all and Cheryl, Chris, Bethan, Archie, Katherine, Pat and Denis Lannon for supporting me in this work.

Abstract

Design tool approaches for investigating energy use at an urban scale have traditionally three problematic issues regarding their implementation: 1) overly simple simulation methods; 2) the complexity of managing large amounts of input data; 3) outcomes that are not easily visualised. My research aim in the papers within this collection was to investigate the issues regarding modelling the energy use of larger numbers of buildings using detailed simulations techniques.

This thesis brings together the papers to describe the research and case studies undertaken. It demonstrates the implementation of the new methods I have created including: hourly energy modelling at an urban scale; parametric analysis; pattern recognition and design analysis. The use of these methods and techniques is evident throughout the papers and combined outcomes show the possible shape of an early stage urban scale design tool. The methods have been explored through a series of international case studies.

The research described in this thesis has contributed to the development of energy modelling of domestic buildings at an urban scale. The work in the appended papers has examined the requirements for a design tool that shows it is possible to use dynamic simulation, with detailed data generated automatically in a visual environment. With these attributes the tools developed can be seen as design tools and as such the work has moved the modelling from simple simulation methods based on an inventory of the building stock to more complex techniques. This involves full dynamic simulation methods and parametric testing of scenarios that include building fabric, systems, renewable technologies and the temporal nature of retrofit.

Each one of the papers has been firmly based in case studies carried out in the UK, Middle East and China, ensuring that the methods used are transferable and applicable to problems of building in diverse climates.

The outcomes of the research within the papers show that detailed energy modelling can be incorporated into the design process at an early stage, giving guidance to the designer, yet not interfering with the detailed design of the project.

Thesis overview

This thesis is a narrative of research into urban environmental modelling that I have been leading since 1995. It is based on nine peer reviewed papers I have co-authored which are presented in chronological order.

Each paper stands on its own, presenting new knowledge and original research, together they form a larger, long term body of research to create a new approach to modelling the energy performance of buildings at an urban scale. This long term research responded to the gaps in literature, the needs of professionals in this field and my desire to push the boundaries of research in this area.

The publication of the papers span seven years from 2007 to 2013, the last four were published together in 2013 and represent the culmination of a number of interlinked research projects looking at the performance of buildings at the urban scale. The papers should be read when indicated within the text of the commentary, to allow the narrative to emerge from the individual papers.

Aims and structure of thesis

The commentary explains the development of urban environmental modelling from an inventory software tool to a piece of software where "what if decisions" can be tested in an "urban scale design tool". My main research aim in the papers within this collection was to investigate modelling the energy use using detailed hourly simulations of larger number of buildings.

Modelling the energy performance of domestic buildings at an urban scale can be undertaken in a "top-down" policy orientated method or a "bottom-up" engineering approach. This thesis describes the development of a bottom-up design tool based on the Energy and Environmental Prediction (EEP) model.

The work carried out in the appended papers has provided evidence of the ability of urban scale modelling to give: confidence in the results; techniques to create data accurately and swiftly; produce results that can be easily interpreted by designers. The thesis demonstrates the implementation of the new methods I have created: hourly energy modelling at an urban scale; parametric analysis; pattern recognition and design analysis. The use of these methods and techniques is evident throughout the papers (figure 1) and combined outcomes show the possible shape of an early stage urban scale design tool. The methods have been explored through a series of international case studies.

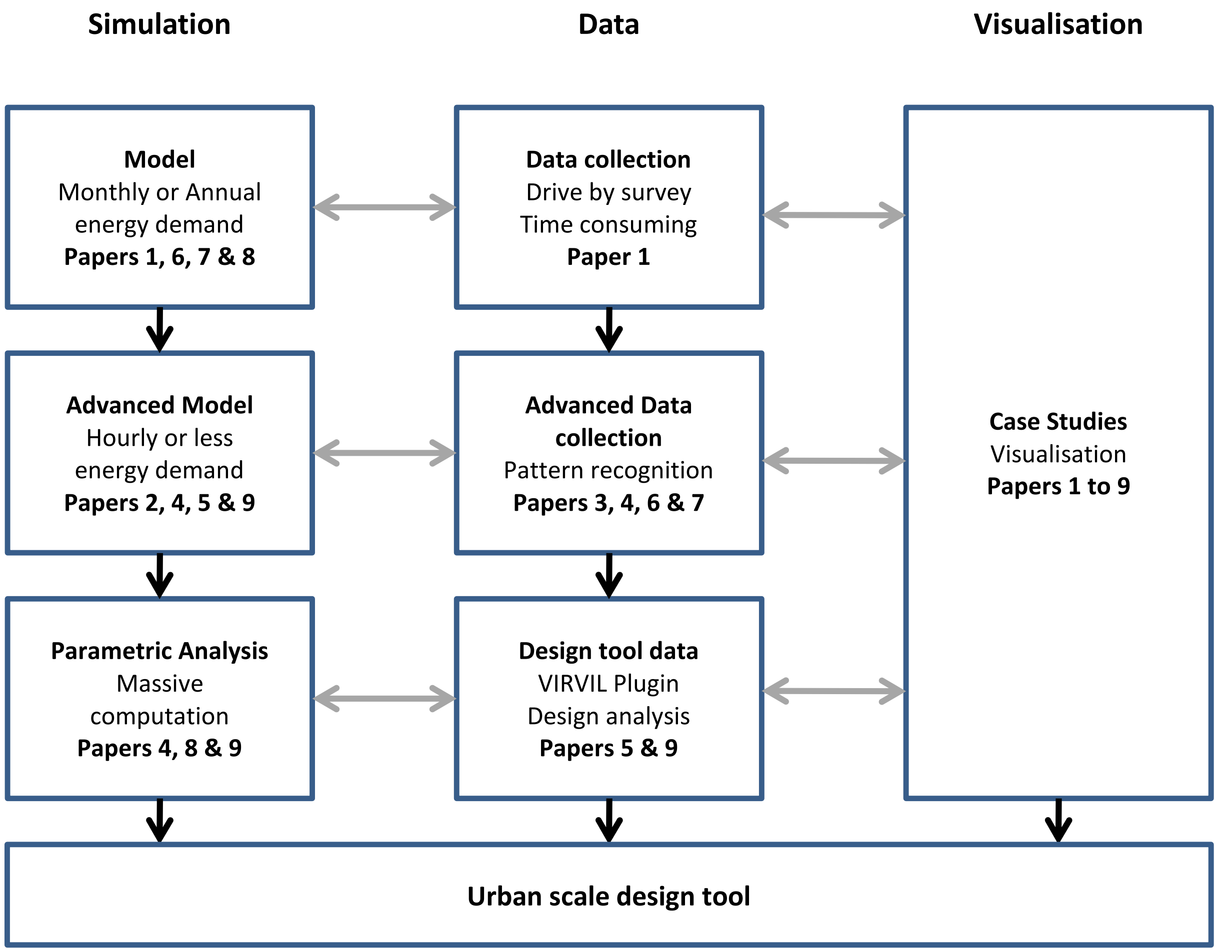


Figure 1 Urban scale design tool development with roadmap of appended papers

To explore these issues this thesis is divided into four sections;

1. Background for the modelling of domestic energy consumption at an urban scale
2. Simulation methods used
3. Data requirement
4. Case studies

Through the sections the emergence of the methods as an early stage design tool for the modelling of energy use at an urban scale is described. The conclusions will reflect on the overall development and the potential for further work in this area.

List of appended papers

1. Jones, P. J., Patterson, J. L. and Lannon, S. C. 2007. Modelling the built environment at an urban scale - Energy and health impacts in relation to housing. Landscape and Urban Planning 83(1), pp. 39-49.
2. Li, Q., Jones, P. J. and Lannon, S. C. 2007. Planning sustainable in Chinese cities: Dwelling types as a means to accessing potential improvements in energy efficiency. Presented at: 10th International Building Performance Simulation Association (IBPSA), Beijing, China, March 2007. Proceedings: Building Simulation 2007. pp. 101-108.
3. Alexander, D. K., Lannon, S. C. and Linovski, O. 2009. The identification and analysis of regional building stock characteristics using map based data. Presented at: 11th International Building Performance Simulation Association

(IBPSA), Glasgow, UK, 27-30 July 2009. Building Simulation 2009 [proceedings]. International Building Performance Simulation Association (IBPSA), pp. 1421-1428.

4. Jones, P. J., Lannon, S. C. and Rosenthal, H. 2009. Energy optimisation modelling for urban scale master planning. Presented at: 45th ISOCARP Congress 2009: Low Carbon Cities, Porto, Portugal, 18-22 October 2009.
5. Bassett, T. Lannon, S., Elsayed, M., Waldron, D., Jones, P. 2012. Calculating the solar potential of the urban fabric with SketchUp and HTB2. Presented at: Solar Building Skins, Bressanone, Italy, 6-7 December 2012.
6. Jones, P. J., Lannon, S. C. and Patterson, J. L. 2013. Retrofitting existing housing: how far, how much?, Building Research and Information 41(5), pp. 532-550. (10.1080/09613218.2013.807064)
7. Iorwerth, H., Lannon, S., Waldron, D., Bassett, T. and Jones, P. 2013. A sap sensitivity tool and GIS-based urban scale domestic energy use model. Presented at: Building Simulation 2013 (BS2013): 13th International Conference of the International Building Performance Simulation Association, Chambéry, France, 25-28 August 2013. Proceedings of BS2013: 13th Conference of the International Building Performance Simulation Association. International Building Performance Simulation Association (IBPSA), pp. 452-459.
8. Lannon, S. C., Georgakaki, A. and Macdonald, S. 2013. Modelling urban scale retrofit, pathways to 2050 low carbon residential building stock. Presented at: 13th International Conference of the International Building Performance Simulation Association, Chambéry, France, 25 - 28 August 2013. Proceedings of BS2013: 13th Conference of the International Building

Performance Simulation Association. International Building Performance Simulation Association (IBPSA), pp. 3441-3448.

9. Jones, P., Lannon, S., Li, X., Bassett, T. and Waldron, D. 2013. Intensive building energy simulation at early design stage. Presented at: Building Simulation 2013 (BS2013): 13th International Conference of the International Building Performance Simulation Association, Chambéry, France, 25-28 August 2013. Proceedings of BS2013: 13th Conference of the International Building Performance Simulation Association. International Building Performance Simulation Association (IBPSA), pp. 862-869

Individual contribution to the papers

The papers described within this commentary are co-authored by 13 different contributors. Within each paper I helped shape the research from the onset and explored the background literature which drives the research. Within this thesis my contributions described in detail are based on the development of modelling techniques and software to enable the use of these techniques. This process has placed me at the centre of the work, allowing me to build research by automating and writing software frameworks, enabling the research to continue. Neither my work or co-authors work are inseparable, but together they have allowed the research in this area to flourish and gain momentum.

Background

The development of the Energy and Environmental Prediction (EEP) model started in 1994 as part of the Engineering and Physical Sciences Research Council (EPSRC) funded project “To develop a model for energy and environmental planning for sustainable cities”. The domestic energy sector was the focus of the early work on EEP as a response to the Home Energy Conservation Act (HECA) (DoE, 1995). This legislation had required that local authorities show a significant improvement in housing energy efficiency, and hence Carbon emission reductions. To help local authorities, software and databases were developed to allow them to track the improvements made. One such software tool was created for the National Assembly for Wales to allow the collection of HECA data “HECA Monitoring Program” released in 2001. At a UK scale the Energy Saving Trust were commissioned to develop a national database of home energy efficiency by the UK Government in 2001 (Energy Saving Trust, 2010) and the outcome of this was the Home Energy Efficiency Database (HEED).

The EEP model focused on the existing building stock and as such it considered the options for retrofit rather than the impact of new buildings on the overall Carbon emissions. In addition, the term “urban scale modelling” in this work responds to the idea that an area is managed by a community organisation, local or regional government or property developer and, as such it is defined as a group of buildings that is much larger than a street up to the scale of a region of a country.

The initial work undertaken to develop the EEP model shows that there is a need to evolve from an inventory software tool to a piece of software where “what if decisions” can be tested in an “urban scale design tool.

Design tools to model the energy demand of buildings

The use of simulation tools to model the energy demand and supply of buildings as part of the design process is well documented, but the use of software tools by designers also shows a lack of trust in these tools (Attia et al. 2009, Zapata Poveda, 2014) and the lack of functional software interfaces (Punjabi 2005). The requirements for an effective design tool are also emerging (Srivastav et al. 2009), allowing the development of integrated design tools they must:

- allow the quick testing of design hypotheses
- give confidence in the results through reliable simulation methods
- require the minimum user data input
- have simple visualisation techniques for the outputs through case studies

Generally bottom up engineering modelling of urban scale energy demand has been undertaken by simple modelling tools, data collection based on survey work, and the visualisation of outcomes through case studies (Swan and Ugursal 2009). This thesis will address these hypotheses when designing at the urban scale rather than individual building scale.

Modelling at the urban scale

Modelling the energy consumption of domestic buildings at an urban or regional scale has traditionally been undertaken in a top-down policy orientated way, where the gross energy consumption data provided by the energy suppliers is used as a starting point (Swan and Ugursal 2009). This data is then analysed using stock surveys to give average composite buildings that can be analysed (Gouldson et al. 2012) using building modelling techniques. This top-down approach is reliant on historical data to produce predictions, rather than based on building physics modelling. This method has inherent difficultly in dealing with new technologies and changes in occupant behaviour and their likely impact on future energy consumption.

Alternatively bottom-up approaches have the potential to model buildings in great detail to take into account complex interactions of building occupants, passive design and active systems. The initial attempts to model urban scale through a bottom-up modelling approach (EEP) (Decorum) (DREAM) are based on steady state models, such as the Standard Assessment Procedure (SAP) (BRE 1998). They predict the energy consumption for archetypes of buildings that represent the building stock to be considered. These models whilst useful, have limited ability to consider the passive and active systems, using utilisation factors to interpret the impact of dynamic building physics interactions such as thermal mass and storage systems (Kavgic et al. 2010).

The concept of an early stage design tool for buildings has been explored at great length, focusing mainly on the building form and fabric. Moving this idea of a design tool for urban scale early stage modelling has been alluded to by Ratti et al. (2005) but it was limited to simple modelling techniques based on the LT method, in order to deal with the complex nature of data collection and visualisation. Whilst work has been carried out to explore the potential for such a design tool, the combination of advanced modelling (Besserud and Hussey 2011 and Reinhart et al. 2013), urban scale data collection and parametric testing, has still to be explored fully.

The EEP model – a starting point

EEP has been developed at Cardiff University since October 1994 with funding from the EPSRC (GR/K19181/01) with support from the Welsh Development Agency. Further development of the model took place with EPSRC funding (GR/L81536/01), in collaboration with De Montfort University, Leicester, University College, London and Queens University, Belfast, to incorporate air pollution dispersal and a health sub-model, and also to look at the implementation of the model into the local authority workplace. The EEP model was the central focus of the Housing and Neighbourhoods and Health (HANAH) project (MRC and EPSRC G9900679) which measured the impact of the urban built environment on health outcomes. The EEP modelling techniques have recently been developed through a further EPSRC funded project titled, “The classification and analysis of regional building stock characteristics using GIS” (EP/E020100/1), and the development of models that can test the visions of 2050 created during the Re-Engineering the City 2020-2050: Urban Foresight and Transition Management EPSRC project (EP/I002162/1).

The EEP modelling technique based on archetypes has also been developed through a number of small research projects investigating the potential for low carbon master planning, to include dynamic simulation methods such as HTB2 (Lewis and Alexander 1990).

Throughout the development of the EEP model the work has been timely and significant in expansion of research within the area of urban scale modelling. In a recent review (Sanaieian et al. 2014), EEP was still considered one of the primary methods for modelling energy performance of buildings at an urban scale. Kavgic et al. (2010) described the model as an exemplar and base their work firmly on its achievements.

Simulation methods for energy demand at the urban scale

Model development, evolving from simple to advanced (figure 2) is described in the sections that follow where, beginning with the EEP model we move into the use of dynamic simulation models such as HTB2, and finally the development of parametric testing

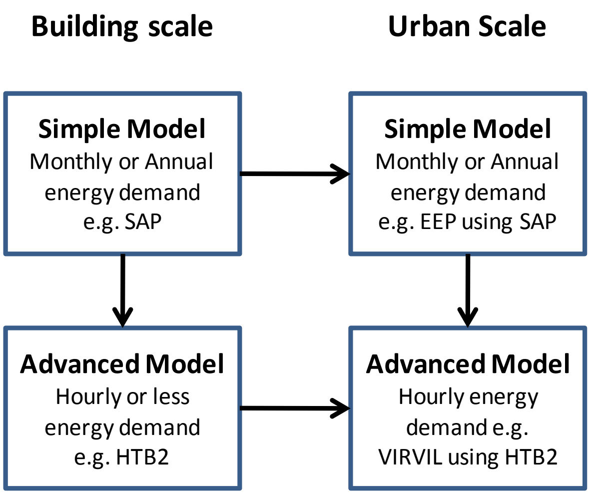


Figure 2 Development of models for building energy simulation

Simple model

The development of the EEP model through the research work, presented in Paper 1 is the starting point of this PhD submission [Please read Paper 1 for more details]. In particular the paper describes the implementation of EEP in Neath Port Talbot, Wales, UK. The model is used within Paper 1 to show the benefit of a targeted energy efficiency programme (figure 3), where building classification allows the simulation of the impact of suitable cost effective energy efficiency measures. The modelling had also been expanded to include the representation of health risk factors for accidents in the home, mould growth risk and neighbourhood quality.

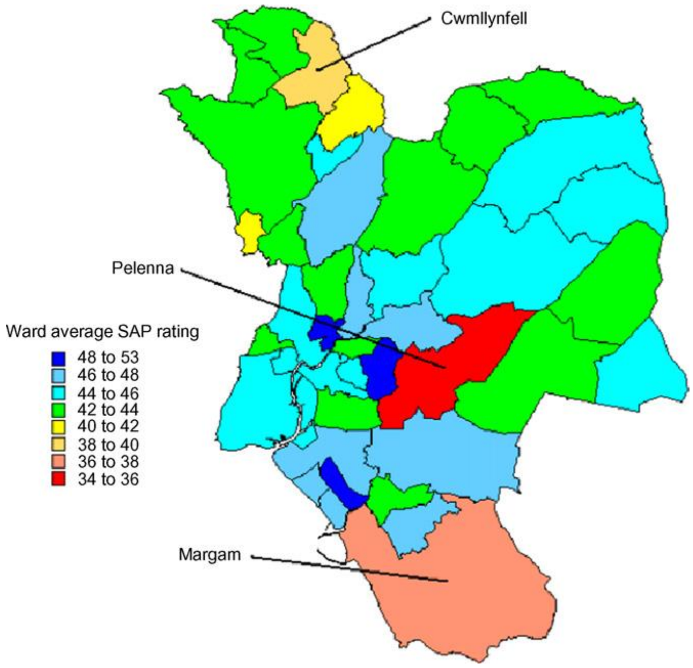


Figure 3 Typical output from the EEP model Average SAP results at a ward level indicating wards with poor SAP ratings

Of particular interest Paper 1 Section 2.2 shows the background data used to create a spreadsheet of all the permutations for energy efficiency measures of the 100 house clusters for different fuel and heating systems (gas central, electric storage heaters, solid fuel central, oil central, gas room heaters, electric room heaters and solid fuel room heaters). The cluster results developed by the fuel mix calculator took advantage of a survey within the study area to give better results for SAP rating and carbon emissions. Other studies regarding energy consumption at urban scale do not mention the fuel used (Ratti et al. 2005) or assume that the heating is provided by main gas supply (Gadsden et al. 2003, Gupta 2009). The outcome of the fuel mix modelling is to enhance the simple SAP/BREDEM modelling usually undertaken at this scale.

The initial work using the SAP model has focused on the Carbon inventory type of modelling. In an effort to explore the use of the SAP model design process a simplified interface to SAP (Crobu, et al. 2013) was developed. The use of the SAP model by designers has been limited to the achievement of building regulation compliance by the complex nature of the worksheet underlying the procedure. My contribution to the software and Paper 7 is the development of the SAP calculation engine, which can be accessed directly through the internet, allowing the EEP model to be applied in a more rapid way and as such it can be considered as a design tool.

Advanced model

The new EEP interface and sub-model described in Paper 2 shows a combination of the outcomes of a simple Dynamic Simulation Modelling (DSM) method and the visualisation of the results through Geographic Information Systems (GIS) to predict the impact of interventions on a number of types of buildings in China [Please read Paper 2 for more details]. The case study used a site within Xi'an city of more than 50 buildings that could be categorised in five built ages. The interface was stripped down to a single sub-model that incorporated the data required to represent the HTB2 results, similar work had been undertaken by Ratti when combining the simple simulation tool the “LT method” and urban scale modelling (Ratti et.al. 2005).

The outcomes of pre-processed HTB2 simulations are shown as a map that can be varied according to the efficiency measures proposed. This is a step towards a more detailed approach for urban scale modelling. As a proof of concept it addresses some of the potential combination of dynamic simulation results with the EEP “what if” methods, but also highlights issues around the compilation of the more detail data requirements for DSM methods.

Further development of urban scale modelling is shown in Paper 4 which describes the process undertaken to provide guidance for plot planning for a large development [Please read Paper 4 for more details]. The task was based on limited early design information about the site which consisted of plot shape, plot size, the height of the buildings in the plot, the widths of the roads surrounding the plots and a classification of intended use (for this work they were commercial, residential and institutional types of uses).

As the project was in the Middle East GIS software was used to classify each plot in terms of overshadowing potential from surrounding plots. The next step examined the local energy efficiency building practices and proposed improvements on these using HTB2 as the engine for calculation of cooling load. The results were pre calculated like the work in Paper 2, but in this instance the use of more detailed classifications allowed the outcomes to be more detailed giving greater confidence in the application to individual building plots. The classification of the urban environment based on solar access show this technique can be consider as an early design stage tool.

The next step was to provide an environment where designs (Attia et al. 2009, Srivastav et al. 2009) can be explored. The combination of DSM and urban scale modelling is explored in Paper 5 which presents the combination of an early 3D design tool, SketchUp, and HTB2 [Please read Paper 5 for more details] called the VirVil Plugin. The HTB2 simulation model is non-geometric in the way it interprets a building model and as such it only considers energy flows as links between fabric elements. Therefore, multiple buildings can be modelled in one run as they can be disconnected thermally within one model, which allows the more efficient simulation of an urban environment; for example one weather file can be used to save computational effort. The SketchUp software has a scripting language that allows creation of interfaces to other software such as embedded web pages and external spreadsheets. My contribution to this paper was creating and enhancing the interface by displaying the shading mask for each face of the modelled built environment (Figure 4) and allowing the software to act as a design tool by visualising the results within the interface. This analysis was taken further by a link to Microsoft Excel to produce an overall energy consumption results spreadsheet.

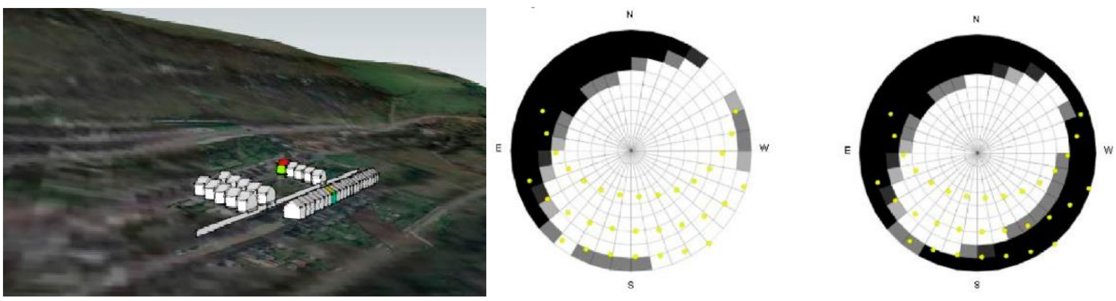


Figure 4 Examples of SketchUp based model outputs, modelling the terrain (left) and the resulting shading masks (right)

Parametric modelling

Parametric testing uses the concept of many variants combining to produce a design space within which the designer can explore design options. The use of advanced simulation can be taken further by running multiple variations of fabric, system or building typologies to explore the simulation space. Paper 4 gives the variants on an existing design. In this case there are 7,200 cases, based on 3 overshadowing, 5 external fabric types, 6 internal gain schemes, 8 orientations and 10 floors within each building plot.

The results were presented at a plot level and at an individual building level. The final task was to explore the potential for providing guidance for individual plot planning in a semi-automated way.

Considering the impact of overshadowing, fabric design and internal gains at an early design stage for plot guidance in a large development can have significant impacts in the reduction of cooling loads in hot climates (Figure 5).

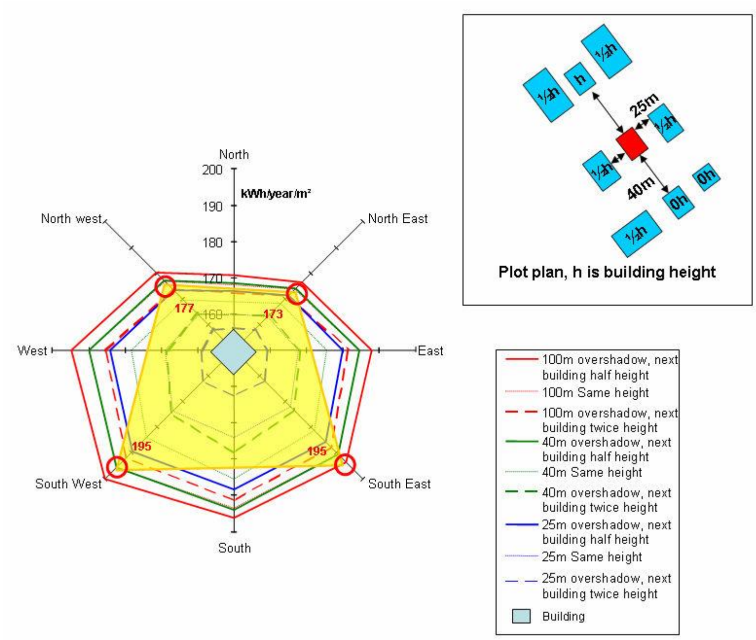


Figure 5 Example plot radar diagram cooling load for different orientations and overshadowing

In Paper 4 my contribution was the creation of the site input data from the limited information available for a proposed development, the simulation of the 7,200 runs and the compilation of results at both building and plot level. In particular new techniques were produced to provide simulation control. This was undertaken using text replacement scripts (Fragaki et al. 2008, Zhang 2009), which use simple text editing software to replace certain text within the input files of HTB2 to produce the variations required.

The variants run in Paper 4 are represented through static graphics in a report; although this is useful as a final product it does not allow the reader to explore the interactions. Papers 8 and 9 show the methods I created to allow the user to alter the scenario to assess the impact on energy demand or carbon emissions. Within these papers, the interfaces I used have sliders based on the work of Crobu et al. (2013).

In Paper 8, I created urban energy demand pathways towards 2050, which were based on work by UK Energy Research Centre (UKERC) and the Carbon Trust [Please read Paper 8 for more details]. As in the EEP model, groups of houses are then modelled using the SAP technique to give a baseline or start point. From this baseline these groups of houses are then modified to improve their energy efficiency, renewable energy supply from roof mounted photovoltaic panels and taking into account the potential changes in the occupant's behaviour. In this example it has been assumed the occupants might accept low inside temperatures by wearing more clothes. The prediction of energy use for each of these modifications is then undertaken and applied to each of the houses in the sample area, in this case most of the houses in Neath Port Talbot, South Wales (around 55,000).

Occupant behaviour also has an impact on whether a particular type of modification will take place. This is represented in this project by trigger points for ten year steps from 2020 to 2050. The trigger points represent this occupant behaviour year by year, and are associated with the likelihood of an occupant undertaking energy efficiency measures. The scenarios with the most energy efficient behaviour will result in all the houses in the area having at least simple energy efficiency and 50% having more costly energy efficiency measures such as external insulation cladding.

The ambitious task was to model the dwellings over 50 years in ten year steps, for 625 different scenarios. A sum total of around 172 million calculations and 9 GB of data were thus achieved. The outcome of these calculations is a web based interface STEEV to the display the outputs (Figure 6). The outcomes of the work show that the energy efficiency of buildings is not enough to reduce the emissions by the 80% required. This work is another use of urban scale energy modelling.

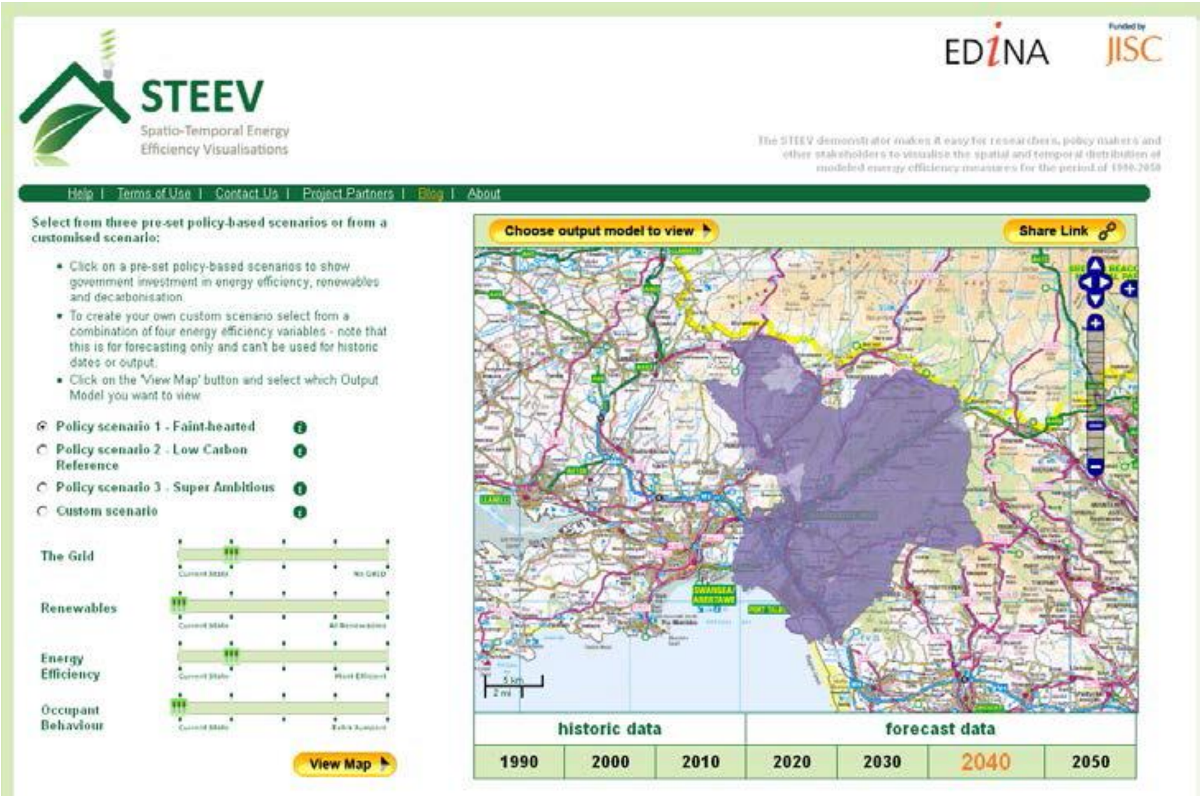


Figure 6 Web based demonstrator – sample map showing percentage CO_2 emissions reductions in 2040 for Neath Port Talbot

The work in Paper 9 shows both the potential for urban scale modelling and parametric modelling (Figure 7) [Please read Paper 9 for more details]. The urban modelling refines the work undertaken in Paper 5 taking the outcomes of the SketchUp plugin and exploring them through a case study in China. The second half of the paper reflects on the parametric modelling and explores it through graphic analysis of the results and the potential for the user to interact with the results through a simple web based interface. The intention of these tools is to explore the potential of an urban scale design tool, based firmly at the plot scale yet allowing the designer to explore the function of form and shadowing on energy consumption and renewable supply options.

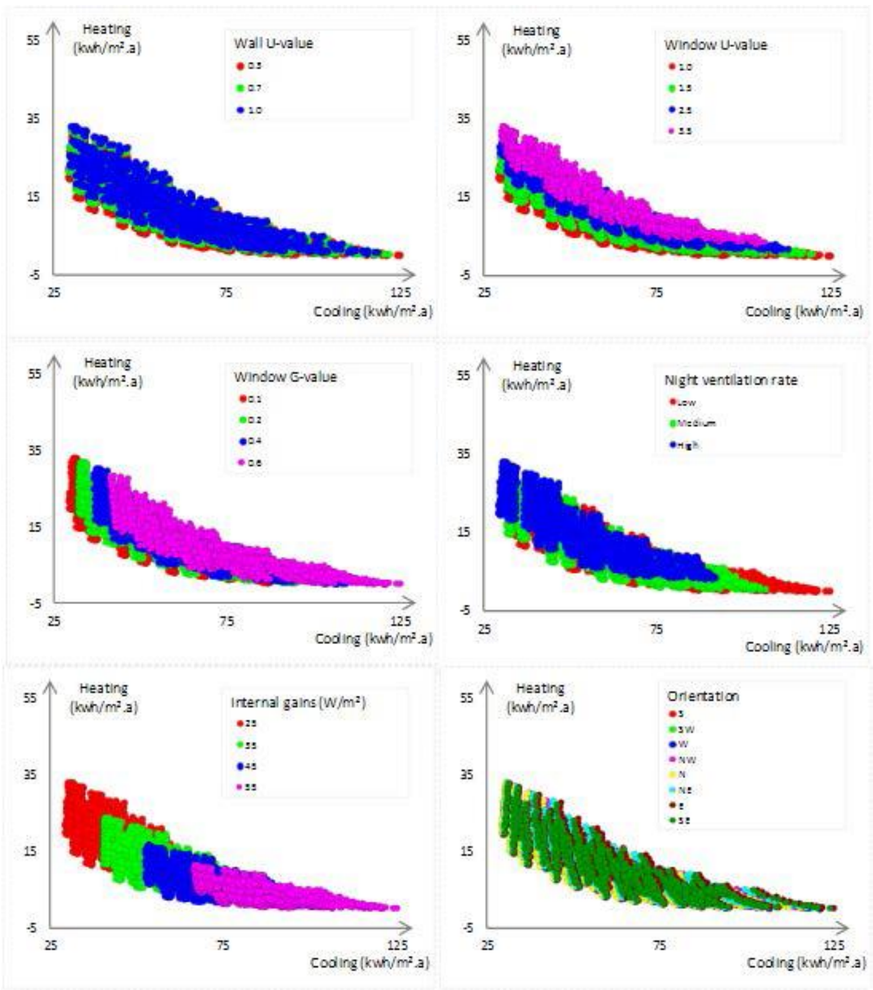


Figure 7 Sensitivity of different variants in relation to their annual heating and cooling energy consumption

Data requirement for energy demand at the urban scale

The data collection for urban scale modelling has been traditionally based on survey work. This thesis will explore the development of map analysis techniques to generate some or all of the data required to model the energy demand of buildings.

Simple data collection

Paper 1 outlines the data required and possible outcomes from the modelling undertaken. The data is generated by the analysis of digital maps and the compilation of information sources on costs and rates of energy efficiency measure implementation.

The domestic sub-model used in Paper 1 was based on the Standard Assessment Procedure (BRE 1998) a tool used to produce a standardised energy rating for UK domestic dwellings. To implement this at a large scale it became apparent that not all the dwellings could be modelled so an archetype scheme was enacted which took data sources and classified the dwelling into one of 100 types of property. To compile a very large number of properties I developed software tools and computer spreadsheets to make the process reliable and repeatable by automating the complex clustering process.

Whilst the results of Paper 1 have proved valuable, the time required to collect the data is seen as the main barrier to wide scale uptake. Paper 1 ends with the aspiration to reduce the data collection process from an onerous 18 man months to a simple automated process. The solution for quicker data collection is shown in Paper 3 showing automation of data gathering is possible.

Advanced data collection

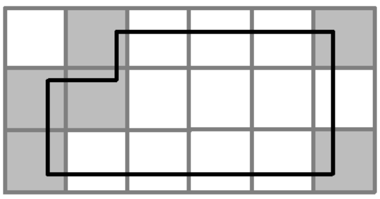
The concept of object recognition based techniques applied to building footprints within a digital map is introduced in Paper 3 [Please read Paper 3 for more details], which discusses a number of methods of recognition applied to a sample area in the UK. The maps are processed and then results compared to "drive by" survey data generated during the creation of the EEP model. Three techniques are described;

- Raster coding uses a simple grid overlay on an "image" of a building footprint using traditional image processing techniques (Fu 1982).
- Vertex coding uses a "robot" to walk around the footprint creating a code based on the side lengths giving a unique "chain code" for each footprint type (Barnsley and Barr 1997).
- Context coding uses the position of the footprint in relation to the objects in the maps, such as roads (Barr et al. 2004) and garden plots.

The success of the object recognition in identifying the building's age is presented for the three different techniques. The success rate varies for the building's age and type of technique. The lowest rate of recognition for any age when considering the best of all the techniques is 55% for post 1980 buildings, one of the highest rate of recognition is 94% for pre 1919 houses. This is in some part due to the nature of the houses built in these periods. Pre 1919 houses were built en masse and to similar patterns, whereas post 1980 construction is a much more heterogeneous stock. It reveals that the automation of the survey technique is not entirely possible, but it can be a starting point for the normal "drive by" techniques.

My contribution to the papers mentioned and the tools generated are described in the following points:

- Polygon creator – Paper 1 Section 2.1.1 of Paper 1 describes that at the time of creation the digital maps (Land Line) produced by the Ordnance Survey were simple line maps. To measure the ground floor area of the property I developed a technique that drew around the area occupied by the property which created a polygon that represents the area (m^2) occupied by the footprint of the building. This technique builds on the work undertaken previously (Rylatt et.al, 2001) using a semi-automated process of selected seed points to start a "robot" moving around an enclosed dwelling outline.
- Raster mapper – The code for this procedure was generated within the GIS it takes the footprint from the map, rotates and sizes it uniformly to prepare it for measurement. The measurement is undertaken by overlaying a user selected grid onto the footprint, where the footprint intersects with any of the cells of the grid it produces a true response; if the cell has no intersection with the footprint a false response is generated (Figure 8). This was an implementation of the techniques described by Fu (1982).



0	1	0	0	0	1
1	1	0	0	0	0
1	0	0	0	0	1

Figure 8: 6x3 raster coding for a building outline.

- Vertex coder -This code is built up the idea of a "robot" (Rylatt et al. 2001) to walk around the footprint edge measuring the sides and creating a chain code based on each side's length (Figure 9). Additional information was generated to help classification including the longest length of a side and the total perimeter.

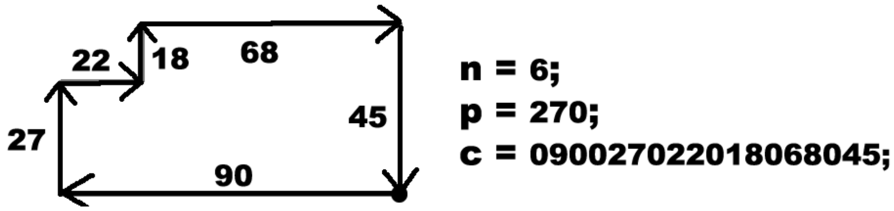


Figure 9: Vertex coding, in dm, for a building outline.

- Context coder – This process considers the building in its group and connection to nearby roads using the geometry stored in the digital maps (Adolphe 2001). To establish if the building is part of a group, a duplicate map of the building footprints is created; this is then subjected to a combination function within the GIS that produces a simplified polygon boundary for all objects. The outcome of this is a row of terraced house footprints, for example 10 outlines are combined into one footprint. This combined footprint is then used to establish the number of connected footprints within it, this information is then pasted into the individual footprints. These techniques were refined to produce information about the surroundings within which the footprint sits.
- Overshadowing characterisation – In Paper 4, the potential for analysing the urban fabric has been explored in Paper 3 and by Adolphe (2001) these allow the clustering of the development plots into groups. Coding was undertaken for each plot with two variables, one for the plot form and the other for the obstruction type viewed by each side of the plot (Figure 10). The clustering allowed the plots to be reduced from 1,131 to 80 plot form types and 83 obstruction types.

Figure 10: The individual colours are clusters that represent how much shading is seen by each façade; the same colour plots have the same shading

Paper 3 and 4 express techniques to classify buildings and also introduces the idea of object orientation within commercial software that is to say that the map objects are analysed as if they are related to their surroundings. This is used later within SketchUp to identify a building and its faces.

Design tool data

To embrace the idea of an urban scale design tool, data generated in a GIS has been moved to data generated within early stage 3D design tools such as Trimble SketchUp (figure 11).

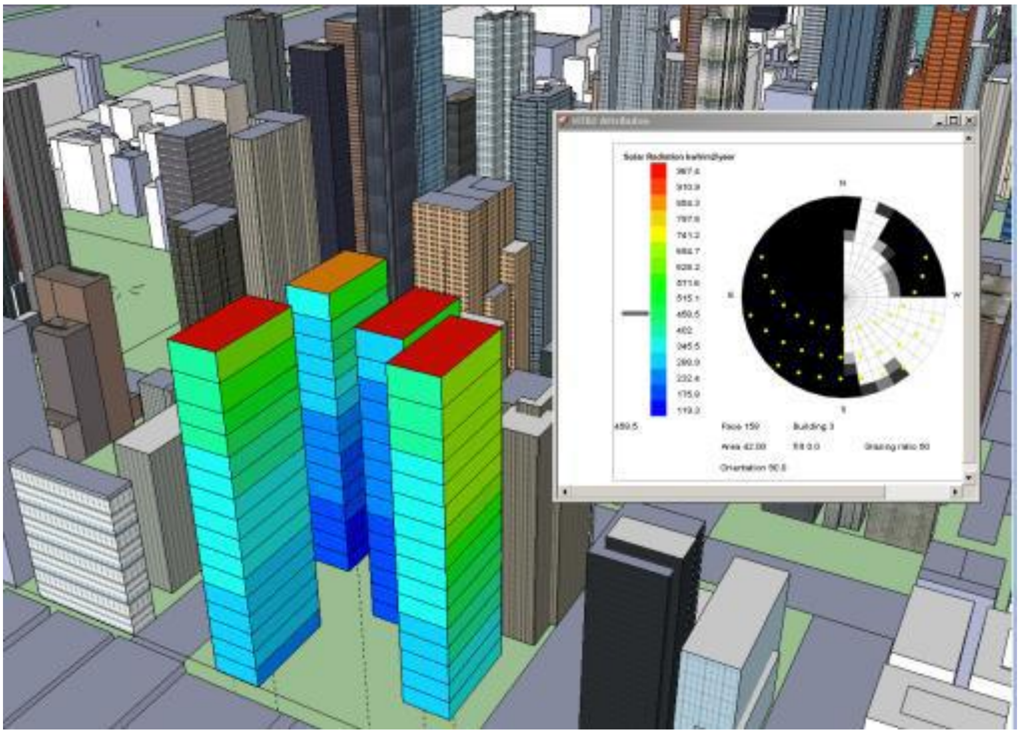


Figure 11 Results based on data generated within early stage 3D design tools such as SketchUp (Waldron, et.al., 2013)

Paper 5 describes the information that allows accurate shading and reflection masks to be created. In this paper the authors describe the potential outcomes possible using this type of modelling, building on the scripting work we undertook to create the shading and reflection masks.

The VirVil plugin allows access to the internal data within SketchUp. The work I undertook extracted this information into a series of Microsoft Excel spreadsheets to provide a simple results file for the extraction of element information to construct embodied energy calculations and renewable energy potential assessments.

Case studies of energy demand at the urban scale

The modelling of the domestic building stock has been undertaken using simple models and data in the UK. The modelling of the urban scale using advanced modelling and parametric modelling has been undertaken in the Middle East and China. This work has explored the interactions of overshadowing, climate and construction types. The interactions have been visualised in Papers 4 and 9, and interfaces considered in Paper 9.

The work has highlighted case studies in the following locations:

- Neath Port Talbot County, United Kingdom
- Cardiff, United Kingdom
- Xi'an, China
- Ras al-Khaimah, United Arab Emirates
- Chongqing, China

In addition, modelling based on the work described here has been used in other case studies throughout the world:

- Banham, China
- Hanoi, Vietnam
- New York, USA
- Riyadh, Saudi Arabia
- Taipei, Taiwan

The outcomes of the modelling undertaken in the papers that form the basis of this thesis show the progression from a simple bottom-up modelling to an urban scale design tool. Initially the model uses GIS techniques to visualise the data which can help users to explore the results more readily, and target resources appropriately. In the later papers early stage design tools are used to visualise the outcomes of design choices.

Papers 1, 2 and 4 are based on the GIS techniques to visualise the data and results. The outcomes of the work in Paper 4 show that careful consideration of the design can lead to reduced cooling loads by up to 5 to 17%, if overshadowing by adjacent buildings is considered. If internal gains are reduced, cooling demand can be reduced by 26% to 40%, and if fabric design is executed in a careful way the reduction is 7% to 20%. Overall if these are combined the reduction can be in the range of 38 to 54%.

In Paper 6, the cost implications of domestic retrofit are examined through three case studies, all of which use the EEP model as the simulation environment. This paper combines the simulation results from a proposed refurbishment programme by Neath Port Talbot County Council, a blanket intervention based on door knocking every household and the intervention through the Welsh Government "Arbed" scheme (Welsh Government 2012). [Please read Paper 6 for more details] All the programmes are based on survey data and the EEP model is used to predict the Carbon emissions savings related to the interventions. The cost data has been provided by the organisations involved.

The model used both existing and new survey data generated through a number of sources. The "Arbed" scheme data was limited and as a result a rapid "Google Street View" survey was implemented. This combined existing data from the previous EEP surveys with data generated from Street View drive by (Wilson 2012) and data from the Ordnance Survey Master Map collection.

The results of this work show that the shallow retrofit can deliver around 20% saving; the deep retrofit can deliver around 80% savings. The task highlighted by this work is the middle ground where the costs to deliver retrofit on a substantial scale can be affordable (Figure 12). This work develops guidance on the cost effectiveness of retrofit measures. The transition from shallow to deep retrofit shows the limitations of the measures available to deliver the targets required.

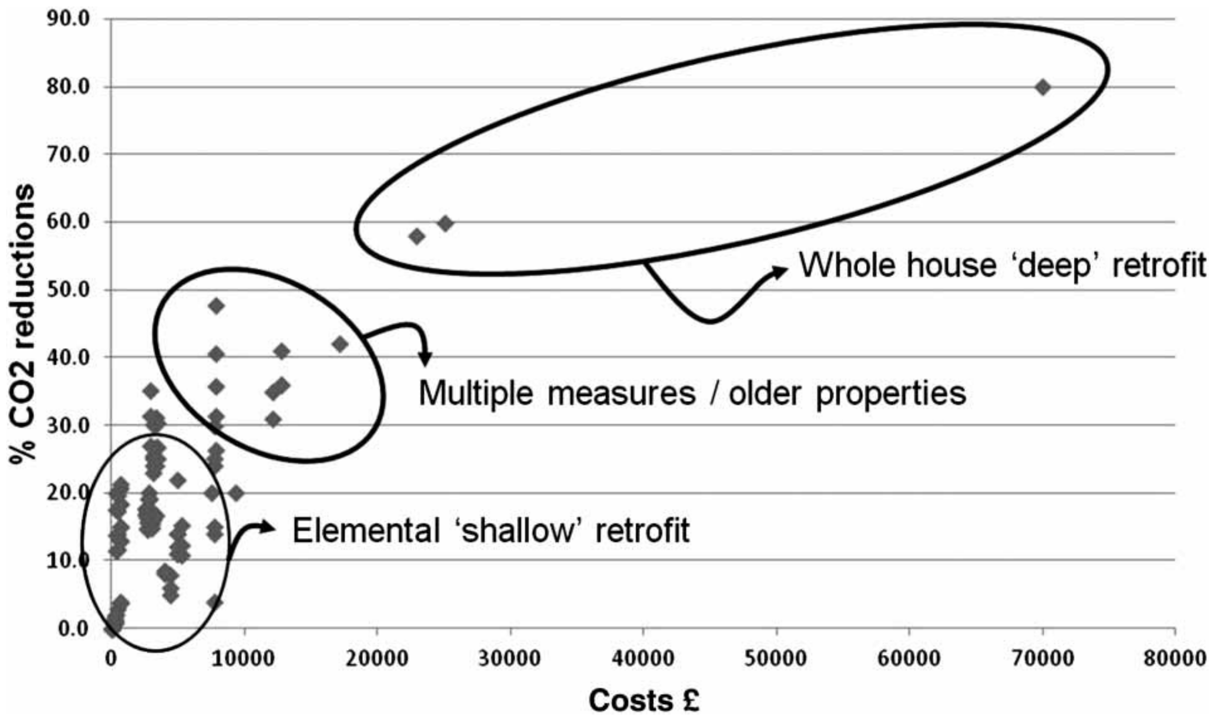


Figure 12 Summary of costs versus savings for retrofit programmes

The performance of the SAP model at an individual building level has been questioned by researchers (Kelly et al. 2012) other work on the BREDEM model has shown the potential for the SAP model to work at Middle Layer Super Output Areas (MSOA) scale, roughly 2,000 to 6,000 households (Mavrogianni, 2009). Paper 7 combines the EEP modelling technique with existing data sources to test the hypothesis that SAP works at the Lower Layer Super Output Areas (LSOA) level of around 1,000 households (Figure 13). [Please read Paper 7 for more details] My contribution to this work, building a new SAP model interface, has been mentioned earlier, and as a result the paper shows that if the model is adjusted to reflect the more likely lower internal temperatures and the impact of the overestimation of solid wall U-values, then there is a strong correlation between modelled and actual energy use. This provides confidence that the work reflects the state on the ground and with this in mind the value of modelling at an urban scale is clearer.

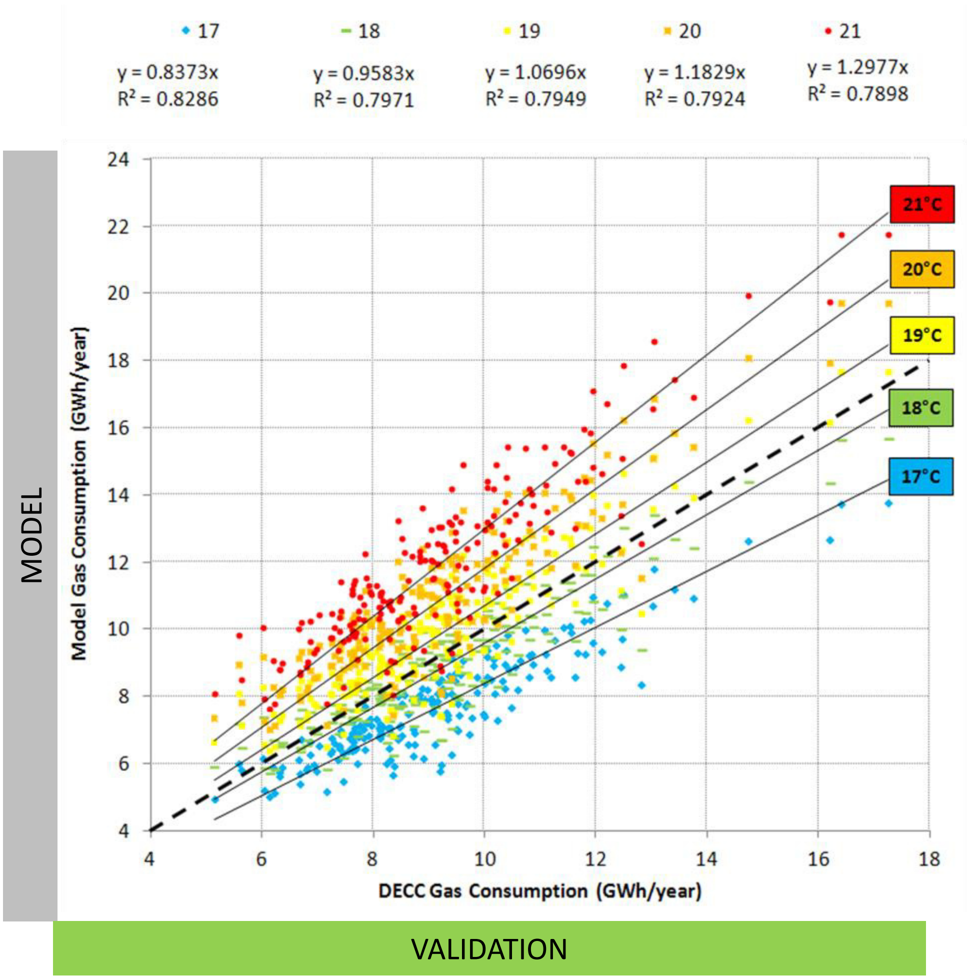


Figure 13 Predicted gas consumption against DECC gas Consumption for LSOAs

Conclusions

The research described in this thesis has contributed to the development of energy modelling of domestic buildings at an urban scale. The work in the appended papers has examined the requirements for a design tool. They have shown that it is possible to use dynamic simulation, with detailed data generated automatically in a visual environment. With these attributes the tools developed can be seen as design tools and as such the work has moved the modelling from simple simulation methods based on an inventory of the building stock to more complex techniques. This involves full dynamic simulation methods and parametric testing of scenarios that include building fabric, systems, renewable technologies and the temporal nature of retrofit.

This process has the advantage of allowing designers to explore the context of the buildings, ensuring that they consider overshadowing and massing options at the master planning stage. The outcomes of the modelling can be incorporated into the design process at an early stage, giving guidance to the designer, yet not interfering with the detailed design of the project.

Considering the movement to the more complex models, the data requirements have also been addressed through pattern recognition techniques, clustering using overshadowing and plot form, and the development of easy to use interfaces to early design stage massing tools.

Each one of the papers has been firmly based in case studies carried out in the UK, Middle East and China, ensuring that the methods used are transferable and applicable to problems of building in diverse climates.

The contribution that I have brought to all of these papers is the combination of building physics and software development, these formed the spine of the research undertaken. Each step of the process has involved researching software techniques, from pattern recognition to ray tracing, and combining these with the physics of the energy demand simulation, be it solar radiation to fabric type. Whilst the work described in the appended papers has been of a collaborative nature the work that I have done has been combined to provide a pathway for energy modelling at an urban scale.

Further work

The work within the papers appended has been from simple to complex modelling and building from basic to more sophisticated datasets. Both these areas of research have more work to do, the potential to simulate the built environment is gaining momentum and computing power is increasing to match these developments. The data requirements of models are limitless, but the capacity for society to develop data is also gaining pace, through smart phones, and “the internet of things”. The next steps are to take these range of developed models, along with increased access to data, and address the issue of communicating energy efficiency potential to users. The potential exists to use devices that might gather data and model the results, using interfaces that can be easily understood and have a life of their own, including apps, websites and other platforms. The potential now exists to build models that incorporate different “lenses” to view them from, expert, financier, to lay person. This is the next challenge and forms the basis for further work on urban scale energy modelling.

The modelling techniques described within this thesis can be applied in a wide range of settings including large scale urban developments, retrofit programmes, and ecocities and show the huge potential to reduce energy consumption and Carbon emissions. The outcomes of the work are targeted at the managers of the building stock, local/national government, developers or owners of large building portfolios.

Appended papers

Paper 1 - Modelling the built environment at an urban scale - Energy and health impacts in relation to housing

Jones, P. J., Patterson, J. L. and Lannon, S. C. 2007. Modelling the built environment at an urban scale - Energy and health impacts in relation to housing. Landscape and Urban Planning 83(1), pp. 39-49.

My Contribution in this paper

The research presented in this paper required the energy modelling of a large number of dwellings. Based on the literature and the available tools, I developed the domestic sub-model used in this paper to answer the significant research question "How to model buildings at an urban scale?". The model was based on the Standard Assessment Procedure (BRE, 1998) a tool used to produce a standardised energy rating for UK domestic dwellings. To implement this at a large scale, I established that not all the dwellings could be modelled so an archetype scheme was undertaken, which took data sources and classified the dwelling into one of 100 types of property. In order to compile a very large number of properties I developed software tools and computer spreadsheets derived from the literature to make the process reliable and repeatable.

The tools generated were a footprint polygon creator and a fuel mix SAP model for the domestic energy supply modelling.

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6th November 2014

To whom it may concern,

Regarding the paper*:*
Jones, P. J., Patterson, J. L. and Lannon, S. C. 2007. Modelling the built environment at an urban scale - Energy and health impacts in relation to housing. Landscape and Urban Planning 83(1), pp. 39-49.

I worked with Simon on the EPSRC funded projects related to the Development of the EEP model this paper is a result of the research undertaken. The domestic sub model used in this paper forms the starting point of his PhD submission. The model was based on the Standard Assessment Procedure (BRE, 1998) a tool used to produce a standardised energy rating for UK domestic dwellings. To implement this at a large scale it became apparent that not all the dwellings could be modelled so an archetype scheme was enacted which took data sources and classified the dwelling into one of 100 types of property. To compile a very large number of properties Simon developed software tools and computer spreadsheets to make the process reliable and repeatable. The tools generated were a footprint polygon creator and a fuel mix SAP model for the domestic energy supply modelling.

If you have any questions regarding this matter please do not hesitate to contact me.

Yours sincerely,

Prof Phil Jones

Paper 2 - Planning sustainable in Chinese cities: Dwelling types as a means to accessing potential improvements in energy efficiency

Li, Q., Jones, P. J. and Lannon, S. C. 2007. Planning sustainable in Chinese cities: Dwelling types as a means to accessing potential improvements in energy efficiency. Presented at: 10th International Building Performance Simulation Association (IBPSA), Beijing, China, March 2007. Proceedings: Building Simulation 2007. pp. 101-108.

My Contribution in this paper

The research question described in this paper required a more detailed approach to the modelling of energy demand for dwellings at an urban scale. To answer this question I developed the methodology to link the simulation using the HTB2 simulation engine to the EEP model. In addition a new EEP interface to access this domestic sub-model.

In this research I reduced the EEP interface to a single domestic sub-model, which allowed the incorporation of the outcomes of the HTB2 simulations, and thus it moved from a simple energy model to a complex one. The work I undertook showed that the linkage of complex modelling to urban scale problems was possible.

10th November 2014

To whom it may concern,

Regarding the paper:
Li, Q., Jones, P. J. and Lannon, S. C. 2007. Planning sustainable in Chinese cities: Dwelling types as a means to accessing potential improvements in energy efficiency. Presented at: 10th International Building Performance Simulation Association (IBPSA), Beijing, China, March 2007.Proceedings: Building Simulation 2007. pp. 101-108.

I worked with Simon during my doctoral studies at the Welsh School of Architecture. In particular Simon's contribution to this paper which developed the domestic sub model in the Energy and Environmental Prediction (EEP) model. In this paper HTB2 was used as the simulation engine, to allow the use of this tool Simon developed a new EEP interface and sub model. The interface was stripped down to a single sub model that incorporated the data required to represent the HTB2 results.

If you have any questions regarding this matter please do not hesitate to contact me.

Yours sincerely,

Dr Qian Li

PLANNING SUSTAINABLE IN CHINESE CITIES: DWELLING TYPES AS A MEANS TO ACCESSING POTENTIAL IMPROVEMENTS IN ENERGY EFFICIENCY

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ABSTRACT

This paper discusses a combination of a dynamic thermal model (HTB2) and a regional energy and emission auditing tool (Energy and environmental prediction model) to analyze the energy efficiency potential of different design strategies, in new or renovated projects. The main aim of the model is to enable decision-makers and other sectors in built environment to predict and account for energy use within a region so that overall strategies and schemes could be made beforehand to reduce energy and carbon dioxide emissions. By applying it into a case study in Xi'an city, it demonstrates how this computer-based model package can be functional within local authorities as planning and policy tool to assist sustainable development, especially in guiding to achieve the energy efficiency demand requested by Chinese government.

KEYWORDS

HTB2, Energy Efficiency, Sustainable Planning, Decision-making, Urban scale

INTRODUCTION

The awareness of sustainability in China's housing is growing higher than ever. At the current development and construction speed, China is becoming one of the largest energy consuming countries in the world. Therefore the improvement of energy efficiency has become a crucial problem of China. The nation's economic advances over the past two decades have increased the living standards for Chinese people. After many years of under-development, China's housing development and construction industry have developed rapidly in order to house the continuous population growth and to meet their demand for better housing, and the construction of buildings is becoming one of the nation's prime industries which increasingly has a major impact on the nation's overall economic performance. In 2004, 24.7% of the whole nation's investment was attributed to the real estate market (Ma 2006). In consequence, the domestic floor space completed in urban regions each year is growing at an incredible speed, with the annual floor space completed in urban areas rising by a factor of almost five times over the past 20 years (Figure 1) (Statistics 2005).

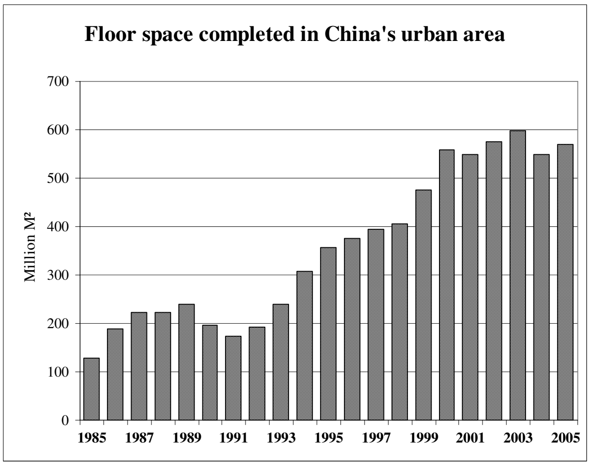

Figure 1: Floor space completed in cities

However, with the fast-track nature of development taking place in China, emphasis has been on the speed of construction, and not on the design of buildings that are energy efficient and provide good environments for their occupants. Housing in China consumes large quantities of energy and most housing is not energy efficiency. For example, in 2003, domestic buildings used about one fifth of the nation's energy consumption and produced 30% of its CO_2 emissions, moreover, the average energy use in dwellings in China are treble that of European dwellings with similar climate (Li Liu & Tao 2004). In order to reduce energy used in houses, the Ministry of Development published 'Guidance for Developing Energy Efficiency Residential and Public Architecture' in 2004 (Ministry of Development 2005. The strategy requires that new domestic buildings constructed in the period of '11th Five Year Plan (Year 2006-2010)' should have a 50% energy saving compared to the housing constructed before 1981, and the energy saving rate for the whole nation is expected to rise a further 15% to 65% by 2020. In some big cities like Beijing and Tianjin city, the saving rate is expected to be 65% by 2010.

However, how to meet these targets is a problem, according to Qiu Baoxing, the vice deputy of Chinese construction committee, only 5% of current buildings are able to satisfy the energy regulation

(Qiu 2006). The major concern now is, without a proper management method, attention from government is not enough, and the lack of detailed way to test and monitor the effectiveness level of different design method on energy performance for the variety of new and existing buildings. Therefore improving the awareness of the decision makers and local government, by providing an energy performance auditing tool is important. Furthermore, it is also necessary to predict the energy consumption and CO_2 emissions, not only of single properties but also the city as a whole.

Hence, in order to improve the urban energy management and planning for a sustainable future, local authority policy makers and managers require knowledge of energy consumption and emissions at a local level, together with the ability to predict how this might change over times as new policies are introduced and new developments are proposed. It will enable them to achieve the targets effectively and spend the investment wisely.

This paper describes the process of generating and comparing the effectiveness of different design modifications at a larger scale, it was presented through an analysis of the energy performance of residential buildings by using a case study in Xi'an city. The analysis is based on computer predictions, relating to the current design and what improvements can be reasonably achieved in line with China's targets for reducing housing energy demand. In order to validate the simulation, results from computer predictions have been tested against measured data.

METHODOLOGY:

Energy performance simulation tools, Geographic Information System (GIS) software and site surveys were used in this study.

The usefulness of thermal simulation and analysis software as both a research tool and as part of the building design process has been demonstrated many times. HTB2 (Alexander 1996) and the Energy and Environmental Prediction model (EEP) (CRIBE 1999) were used to consider the integration of different design modification aspects. Design tools like those can provide a specialist input, say into predicting the energy performance of buildings, or the prediction of internal environmental conditions. For some time computer models have been available to predict energy use and indoor thermal comfort such as indoor airflow and lighting. Using such specialist tools allows the designer and decision maker to consider design options that respond to occupants' needs and energy efficiency.

HTB2 is a finite different model developed at Cardiff University that is intended for the simulation of the energy and environmental performance of buildings. It is a revised version of the Heat Transfer through Building program (HTB) that was developed in 1971(Alexander and Jones 1996).

Being an investigative research tool rather than a simple design model, HTB2 is able to demonstrate comprehensive operation prediction of internal environment conditions and energy demand of a building, during both the design stage and its occupancy period. It can predict the influence levels of fabric, ventilation, solar gains, shading and occupancy on the thermal performance and energy use of a building (Jones and Alexander 1999).

The EEP model is a computer based modelling framework developed at Cardiff University that quantifies energy use and associated emissions for cities to help planning sustainable cities. The model is based on GIS techniques and incorporates a number of sub-models to establish current energy use and CO_2 emissions produced by buildings (CRIBE 1999).

Each building in the EEP model is linked through the GIS framework and can be accessed and updated from a main menu screen. It presents results in the form of thematic maps that highlight pollution or energy hotspots throughout a region. These can be used to pinpoint areas of high energy use that can be targeted for improvement.

The packages of HTB2 and Energy and EEP program can represent the summary and layout of energy use and CO_2 emission condition at present in both detailed and collectively level on a GIS based system. Moreover, energy efficiency improvement of a single property or a group of buildings that can be achieved by adapting various modifications can also be represented with detail improvement information. These features will be a help to decision makers and designers in planning for sustainable development. First of all, it helps in studying current energy pattern and identifies potential problems. Secondly, the improvement of energy performance in altered building types can also be viewed, this provides users with a chance to pick appropriate methods in order to hit agreed targets. The data flow of the combined software is listed in figure 2.

Computer modelling systems can carry out a range of predictions using the same geometric description of the building. The thermal dynamic energy model HTB2 was used to predict the time varying thermal performance of buildings and EEP represents the annual energy use and CO_2 emission condition

The EEP model acts as a database to store property based information that is collected; presentation of energy usage condition of the site could be represented in many aspects, depending on the amount of input information. In order to plan and predict energy use to a high degree of accuracy a large amount of information is required (Jones and

Lannon 2000). The EEP model has been designed to be transferable to cities worldwide, this study is to explain of how this software can be used in Chinese context, therefore only basic information of the site was inputted.

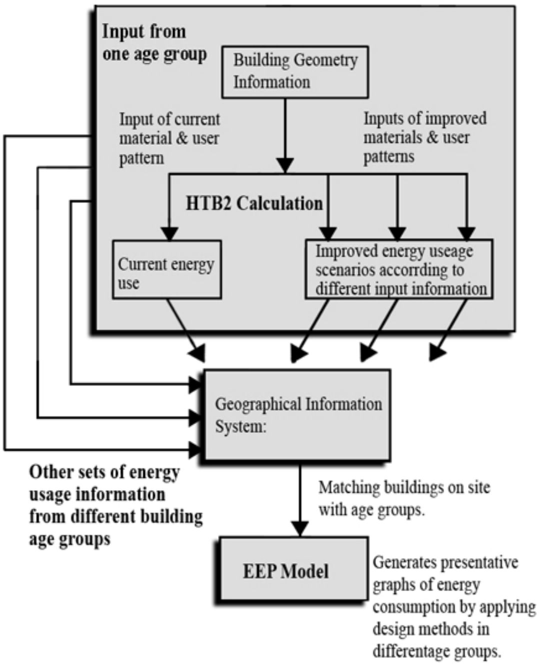

Figure 2: Data flow process of software combination

Due to the limitation of time and funding, the site survey is relatively simple, number of floors, building age, floor area, glazing, insulation method and, buildings' function and age were recorded. The main purpose is to group the properties into different types by using age and built forms. Using HTB2 to estimate the energy consumption, each group has an associated energy usage and CO_2 emission with it. After estimating the energy consumption at present level, analysis is undertaken on the methods that can improve the energy efficiency. The results were presented at a large scale, thus enabling the decision makers to know the effect of the change, according to China's energy efficiency requirement. For instance, to what extent the current buildings perform with the energy aspect and how much they improved from the old standard and the effect of changed heating scheme, from unlimited central heating to the schemed heating.

The results of modelling using these design tools must be useful to inform the design process, and must also be able to be interpreted in a way that can inform high-level decision-making.

CASE STUDY:

A case study is used to explain how the software package work and how the result information can be gathered and represented.

The site is located in south-east Xi'an city; it is the residential area of Xi'an University of Architecture Technology. It contains the area of 14 hectares and more than 50 buildings, however in this study only residential buildings were studied. After analyzing the satellite image of the area (figure 3), all the housing architectures in the site were named and the digital map was made and imported into GIS system, this represents the basic information of the local area.

With the help of local students, a basic survey of the residential buildings in the site was made. The buildings were then sorted by their construction age and grouped into the following clusters: post 2000, 1996 to 2000, 1991 to 1995, 1986 to 1990 and before 1986. In this study, each cluster is assumed to have the similar material information and the same energy performance. Figure 4 is the thematic GIS map summary of the area, the darker colour represents the older buildings. From that we can see most of the housing architectures (forty out of fifty-three) here were built before year 1996，most of which are not in good condition, non-insulated construction and the infiltration through leaky windows are causing high energy demand.

Figure 3: Satellite map of site

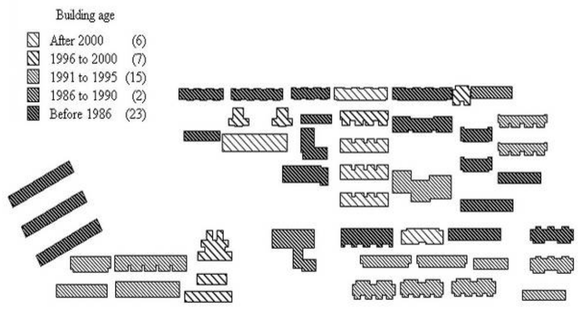

Figure 4: Residential Building Age Pattern of the Site

This study was included as part of a project to develop a strategy for sustainable housing development in Xi'an (Project 2006) (EU Asia Pro Eco project 2006), and a range of typical apartments were measured to assess their energy performance in relation to the current building code and to measure the internal thermal conditions to provide data to inform the modelling process, for example, what internal temperatures are maintained housing in winter. The buildings that were investigated and measured covered a wide range of the existing domestic buildings in different period and they could be used to match the buildings in the surveyed site and use the energy prediction to represent present energy usage of the cluster (it is only used as an assumption and to check the application of the software).

COMPUTER SIMULATION

In order to check the reliability of the thermal simulations, comparisons between the simulations and on-site monitored results were made. The computer simulations used the dynamic thermal models, HTB2 and ECOTECT (Marsh 2004). The generation of thermal models for the example buildings to be used for analysis was undertaken in the Ecotect software and then the models were transferred into HTB2 for energy and thermal simulation.

An example is given below of a typical high rise apartment block ($75m^2$) located at south-west Xi'an city, built in 2004 (figure 5 demonstrate the flat layout and appearance of the building). The building envelope is constructed of aerated concrete blocks with 35mm polystyrene foam internal insulation. The windows are PVC framed double glazing units and the room gazing ratio is around 40%.

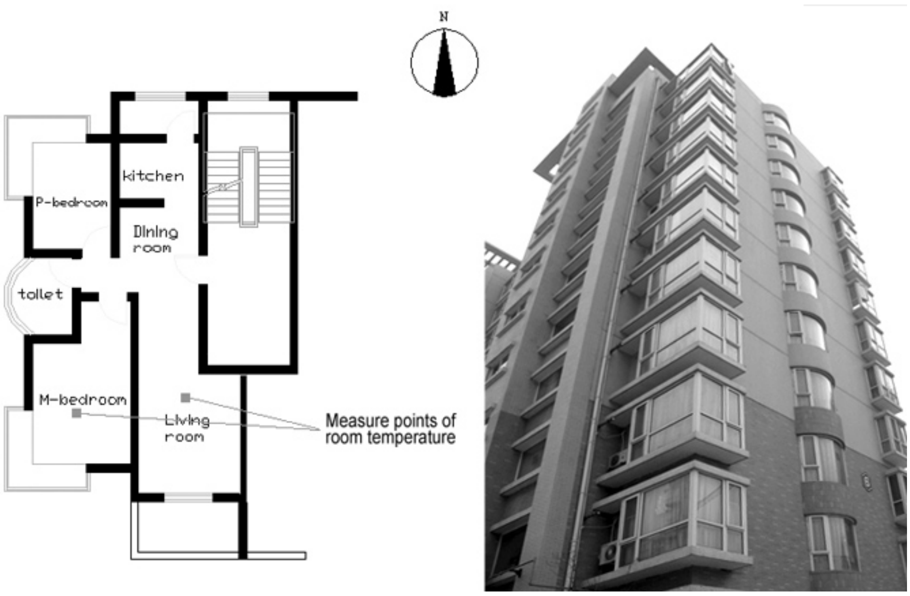

Figure 5: Flat plan and building appearance

The analysis process involved first establishing confidence in the ability of each tool to effectively model the situation being studied. For this, on-site temperature recordings were taken in different rooms within three sample apartments. These rooms were then modelled and simulated over the same time period and the results compared directly with the measurements.

During the measurement mentioned above, typical apartment layouts in middle-level of the residential towers were selected for the analysis, which included: measurements of indoor and external environmental data. External measurements included dry bulb temperature and horizontal solar radiation, these were converted into the appropriate weather data required by the HTB2 model. Internal measurement included air and radiant temperature for rooms as indicated in figure below.

A high level of confidence in the analysis results was very important. The results for room air temperature are presented in figure below along with predictions, using the external weather data for the measurement period. The predicted indoor air and surface temperature from HTB2 modelling compare well with the measured data, difference within +/-1°C. This gives confidence that HTB2 is able to model the performance of the building to satisfactory level of accuracy, to be able to carry out the parametric studies that follow.

After modification and validation of the models,

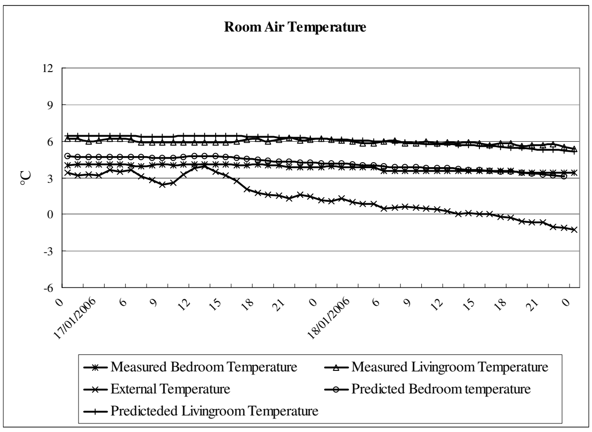

Figure 6: Compare of Predicted data with measurement

energy consumption of the investigated models was predicted. The seasonal weather data in Xi'an city was obtained from the Energy+ website (EnergyPlus) and material information was supplied by Xi'an architectural science University. Information on the construction included: thickness of external wall, insulation type, glazing type and ratio and floor and ceiling materials. For the simulations of the HVAC system operation set point is set to be 26˚C and 21˚C, by adapting the lower band required in <Indoor Air Quality Standard> in China(China 2002). Moreover, energy usage improvement by applying various methods was also carried out. During the comparison of energy improvement, basic building forms and type were kept, while using updated construction information, each type has a representative calculated carbon dioxide emission value yearly from heating energy consumption, the conversion rate is 0.187Kg CO_2 per kWh, the conversion rate comes from Digest of UK Energy Statistics and the heating is assumed to be supplied by using natural gas (Department of Trade & Industry, 2006). The result of improvement of buildings in different period was calculated and put into EEP model script.

EEP is not a traditional calculation method but rather a presentation tool, it enables users to view the overall energy usage of an area and provides a method of comparison between buildings. It helps decision makers to consider different types of energy efficiency methods available when designing new properties or refurbishing existing dwellings.

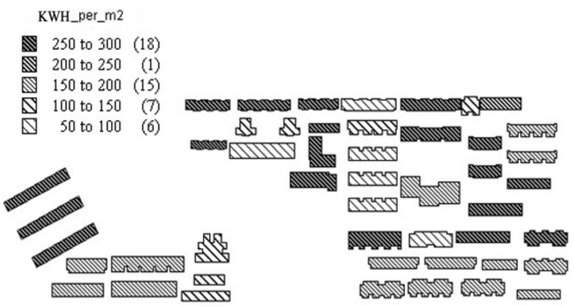

Figure 7: Thematic map of average energy usage

First of all, it represents the current energy use condition in that area. Figure 7 shows the distribution of current average energy usage. The darker colour means the higher energy usage. It can be concluded that older houses have much higher energy consumption rate. The possible explanation could be lack of wall insulation and leaky glazing, figure 8 shows the unsatisfactory condition of housing architecture building in 1980's in the site.

Furthermore, each property can be located in the GIS using postcode, road name and subcategory, therefore the user can identify 'hotspots' of energy use and emissions that can be targeted to make environmental improvements. For example, figure 9 demonstrates the case when viewing the total carbon dioxide emission amount. It is noticed that Building No.12 (circled in the figure) has the highest emission value. Checking the model information index box, the reason can be explained as its high-rise property, therefore when funding for refurbishment is limited, possible modification on this building may have some priority.

Secondly, predictions of potential energy and CO_2 savings that can be achieved by installing various energy efficiency measures into properties can also be made. The improvement of the dwellings and the effect on their energy efficiency can be noted, possible improvement includes: add or improve external wall insulation, change glazing method, changing heating scheme and reduce infiltration rate.

The effectiveness of each modification on dwellings in different age group was calculated by using HTB2 and the results were put into script and the results of any change could be achieved by simply ticking a check box in a dialog box and results are recalculated (figure 10).

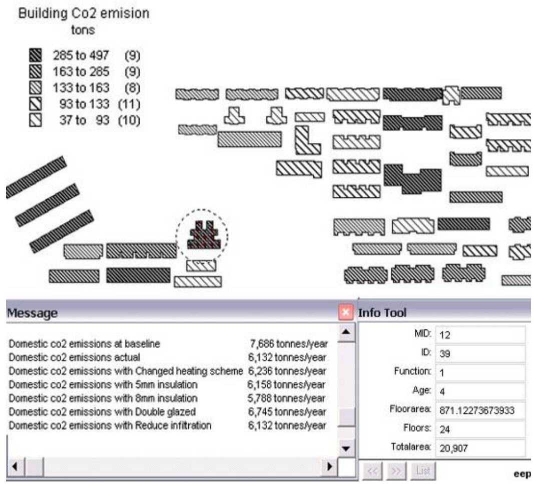

Figure 9: Annual carbon dioxide emissions by building

Figure 8: Out-dated building construction is causing energy inefficiency.

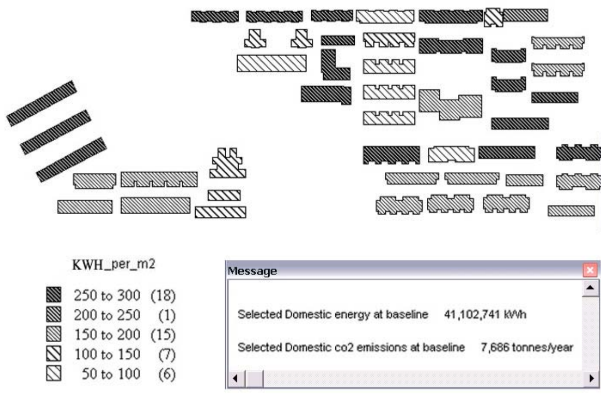

Figure10: Presentation of energy consumption and CO2 emission

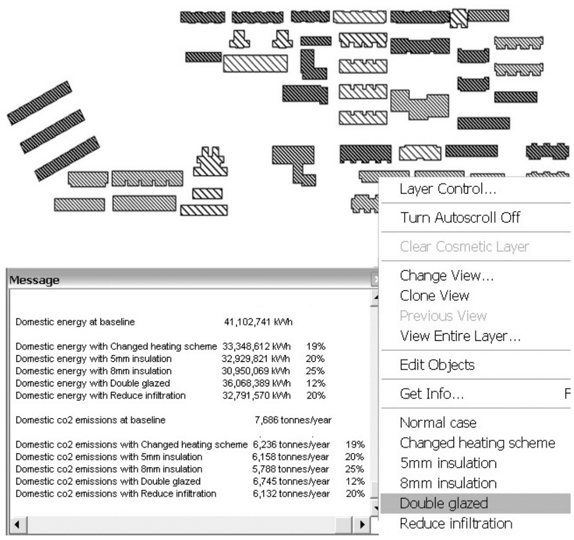

Figure 11: Energy consumption with double glazing fitted

For instance, one of the most apparent features of the housing before 1996 is they are all single glazed, therefore by updating those building to double glazed aluminium windows (U-value 3) from building properties (figure 11), the thematic presentation of heating energy usage can also be updated by recalculation. The heating energy reduce of housing built in 1986 to 1990 and 1991 to 1995 are 15% and 14% respectively, the buildings before 1986 have the largest improvement rate of 18%, the energy consumption of the other two cluster are the same because they are already double glazed.

One modification that can be applied to all building groups is the change of heating scheme. The current continuous 24 hour central heating system is wasting energy by heating the flat while the occupants are not at home. By changing it to period heating according to occupants' schedule (which is from 6 to 9 and 18 to 24 in weekdays and all day in weekends and holidays), the total saving of heating energy could reach 7.7 Million kWh, and the heating cost could be cut down of around 19% and more than 1400 tons of CO_2 emission could be cut. Moreover, by reducing the infiltration rate of heated rooms, the heating energy could be reduced by 7% to 27%, according to the difference of building age. Above improvements are shown in figure 12.

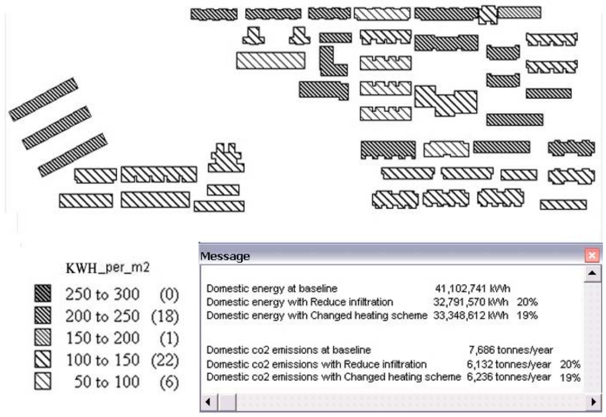

Figure 12: Improved energy efficiency

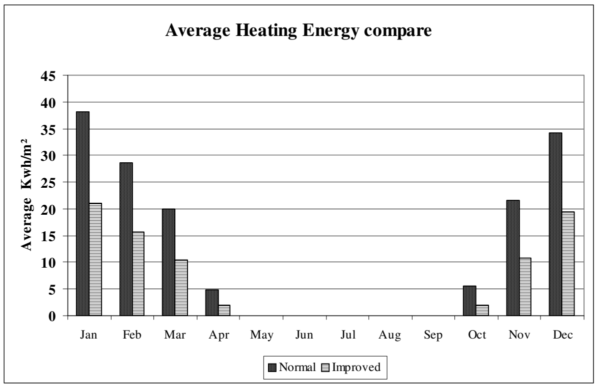

Figure 13: Comparison of heating energy

Results from the case studies have proved that by using combined methods, meeting the building energy saving targets set by the Chinese government is technically achievable. For instance, figure 13 is the comparison of energy consumption in two cases. One is the building that belongs to age group of 1991 to 1995, the other is the same apartment with some improvements. The improvement included 5mm external wall insulation, double glazed window, reduced infiltration rate (from 1.25 to 1 ac/h) and changed heating scheme, the annually energy consumption of the apartments is presented for monthly intervals.. The annual energy saving for heating is about 45%. Table 1 lists the efficiency of energy saving methods that applied in the case study.

However, it is still ambitious for Chinese Government to set these targets *i.e.* 50% building energy saving by 2010 and 65% saving by 2020, given the time planning and the vast area the country

Table 1: Efficiency of design modification

	Age group 1 Before 1986	Age group 2 1986 to 1990	Age group 3 1991 to 1995	Age group 4 1996 to 2000	Age group 5 After 2000	
Current yearly heating load (KWH/M2)	254	206	168	127	93	
Changed heating Scheme	17.9%	18.0%	18.5%	21.3%	22.6%	Energy saving rate of different design modific ation
5mm insulation	25.7%	23.6%	22.6%	19.7%	N/A**	
8mm insulation	31.1%	29.1%	28.0%	23.6%	6.5%	
Double glazed*	18.4%	15.4%	14.3%	N/A	N/A	
Reduce infiltration to 1 ac/h	27.1%	16.2%	7.0%	N/A	N/A	
*When glazing type changed to double glaze, the infiltration rate was also reduced						
**Some modifications are not applicable since the cases already have the methods						

covers. So, in reality, many areas in China fail to perform as expected. The underlined reason for this failure is the lack of an overview tool which will enable decision makers to guide and control the development. Therefore, it is only natural for the government to take a lead in formulating these decision-making frameworks while involving building community and other stakeholders. The decision-making frameworks can include reference to concept designs and case studies, identify what specialist design tools are appropriate and provide continuity across the time scale of a project.

As indicated by experience and practice world-wide, the key is to adopt a holistic approach, through a decision-making framework, that optimises building performance across their physical aspects with regard to a range of sustainable concerns, not least energy reduction, environmental impact mitigation and socio-economic benefit enhancement, throughout the building' life.

Modern building technologies such as computer modelling tools can improve building energy performance in one way or another. By using HTB2 and EEP together, it is able to achieve the following objectives (CRIBE 1999):

- quantify energy consumption for different activity sectors and spatial areas,
- predict future levels of energy consumption,
- calculate the associated emissions from energy use,
- establish a baseline for energy consumption at 1990 levels,
- help assess the cost and other implications of alternative energy management options.

These functions provide the government and decision makers with a chance to guide the design and approve new and effective methods to achieve the agreed energy saving targets.

CONCLUSION

The initial comparative analysis in all cases showed reasonably close agreement between the simulated results and the measured data. In some cases there was variation between the tools and the measured data and sometimes between the tools themselves. This is to be expected and the magnitude of differences was not disproportionate.

China is building at a rapid pace, and attention paid to energy efficiency and sustainable concepts are far from enough. In order to achieve the objective of energy savings in buildings, high quality construction and sustainable design strategy must be applied at design stage. Passive design can bring both energy efficiency and a more comfortable living environment.

From the assessment carried out on existing housing under the ongoing EU project in Xi'an, energy savings could be achieved in line with government standards. However, there is great need for tools that enable the government to overview and guide the development and the application of standard design methods for energy efficiency to a right direction.

The main function of EEP model is to provide an auditing tool for quantifying energy use and emissions in a city to assist in planning for sustainability. Once baseline information for each of the sectors of the built environment has been input into the model, it can be used as a planning and policy tool that will allow local government to select appropriate method and strategies that can improve new buildings or the building stock that is already present.

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Paper 3 - The identification and analysis of regional building stock characteristics using map based data

Alexander, D. K., Lannon, S. C. and Linovski, O. 2009. The identification and analysis of regional building stock characteristics using map based data. Presented at: 11th International Building Performance Simulation Association (IBPSA), Glasgow, UK, 27-30 July 2009.Building Simulation 2009 [proceedings]. International Building Performance Simulation Association (IBPSA), pp. 1421-1428.

My Contribution in this paper

This paper is based on a research idea I developed as part of an EPSRC funded research project to deliver the data required for modelling dwellings at an urban scale. The need to address the quick collection of data had been an outcome of the research that underpinned Paper 1. The research I undertook included the development of tools within a GIS system and was based on a review of object recognition techniques combined with the data issues from the GIS science.

The tools I created include the code for a raster mapper, vertex coder and context coder. These techniques were used to produce information on the context within which the building footprint sits. I was also involved in the creation of test datasets and the statistical analysis.

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To whom it may concern,

12 November 2014

Regarding the paper:
Alexander, D. K., Lannon, S. C. and Linovski, O. 2009. The identification and analysis of regional building stock characteristics using map based data. Presented at: 11th International Building Performance Simulation Association (IBPSA), Glasgow, UK, 27-30 July 2009.Building Simulation 2009 [proceedings]. International Building Performance Simulation Association (IBPSA), pp. 1421-1428.

I worked with Simon on EPSRC funded project titled, "The classification and analysis of regional building stock characteristics using GIS" (EP/E020100/1), this paper is a result of the research undertaken. This paper is based on extensive tool creation within a GIS system. The tools Simon created include the code for a raster mapper, vertex coder and context coder. These techniques were used to produce information on the context within which the building footprint sits. Simon was also involved in the creation of test datasets and some of the statistical analysis undertaken.

If you have any questions regarding this matter please do not hesitate to contact me.

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THE IDENTIFICATION AND ANALYSIS OF REGIONAL BUILDING STOCK CHARACTERISTICS USING MAP BASED DATA

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ABSTRACT

Building energy and Carbon emission calculation methods for regions are of limited use if appropriate input data cannot be economically generated. To enable a wider uptake of regional modelling methods an automated analysis system is required to replace or assist time-consuming and expensive manual surveys of building stock. Building age is an important parameter in estimating energy use and Carbon emissions. In this paper a number of methods to extract information about the built environment from digital maps and use that information to infer building age have been tested against a database of a known large urban region. The methods include different types of shape recognition of plan form and of identification of contextual geography; e.g. distance from entrance to the nearest road.

Tested against samples containing several thousands of domestic buildings from a known region, it was found that the different methods were able to cluster buildings into different form "styles", and that those styles had some correlation to built age. Victorian (pre-1919) age housing was detected with the greatest accuracy, with over 90% in the sample tested correctly identified. This is useful as those older buildings are often the least energy efficient. Success in identification of other eras was less pronounced; although the results are promising, further development of the methods are required.

INTRODUCTION

Boardman et al (2005) estimated that the domestic building stock could deliver a 60% reduction of the UK's carbon emissions by 2050. However, as the proportion of new building stock is small, simply strengthening the building regulations can have only a correspondingly small effect. It is therefore essential to understand the energy performance and carbon emissions of the existing building stock and to be able to predict and test, on a regional level, the potential for improvement.

The Energy and Environment Prediction (EEP) model (Jones, Williams and Lannon, 2000) is a computer based modelling framework that quantifies energy use for regions as an aid to planning actions and incentives aimed at reducing carbon dioxide emissions. The EEP model has proven valuable to its users, for instance in allowing a local authority to target energy efficiency measure to those areas with the greatest need.

However, its use is appropriate only when a region can be described at the level of detail required by the model. Regional energy models such as EEP require an accurate description of the built characteristic of the area in question; as well as numbers and floor areas (both relatively simple to derive) this also includes the profile of housing stock type, age, and fabric characteristics, all required to estimate fuel requirement.

The development of the EEP method showed that an appropriate level of energy and carbon emissions could be achieved by clustering buildings into common types; e.g. "Pre-1919 detached 3-story single family dwelling". Each building in the region to be modelled is then placed in an appropriate cluster in order to estimate its energy use. Building age was determined to be a key concept in forming useful energy performance related clusters; in EEP, building age is defined as the era when the property was built, using date bands commonly used in the UK to describe housing; pre-1919, 1919-1945, 1946-1965, 1966-1980, and post-1980. From the building age characteristic other parameters, such as levels of insulation, uptake of double glazing, or type of heating system, can be inferred.

In application to a real region, this clustering information is acquired at significant expense. Information on built age is, for most local authorities in the UK, not readily available. The data may exist but only in many disparate forms and sources; planning offices, archives, records offices. A manual collation and analysis of those on a large scale (for instance the region considered in this paper comprises 450 square km) would be prohibitively costly. The procedure for the EEP method requires a manual survey to identify the building stock parameters required. This survey is primarily a 'walk by' method, involving the visual identification of each building in the area, coupled with a postal survey covering details such as prevalence of retrofit measures, heating system types and so forth. When this method was applied to the county of Neath Port Talbot in the United Kingdom, where 55,000 dwellings were to be modelled (nearly 100% of the stock population), the survey required an investment of 18 man-months. The author's experiences of this and other surveys have shown that residents are poor judges of their building's age, unless it is very new. We cannot rely on their data alone, and so trained assessors were required.

When well formed, a regional model such as EEP can predict energy use trends with acceptable accuracy, even though the underlying energy model is relatively simple (in the case of EEP, one based on the BREDEM method). Figure 1 shows a comparison that we have made between EEP predictions of the housing energy use for the Neath Port Talbot region, and actual gas fuel use in the area (as determined from BERR data[1]). Each point on the graph is for a "middle layer super-output area"; each contains roughly 3500 dwellings of mixed type and age. This agreement was reached using the fully realised EEP model resulting from the manual survey.

The manual survey method used for this region provided a level of information that was otherwise unobtainable. However an investment in manpower and time on this scale has proved to be a barrier to the wider uptake of the EEP model, or indeed others like it. In order to allow greater access to such modelling methods, there is a need to explore and develop more efficient methods for acquiring building stock information. It is expected that a more efficient survey method would provide similar quality results for a lower investment. Should such improvements become available, feedback from EEP users indicates that detailed regional energy models would find wide-scale application in local and regional government.

BUILT FORM INDICATORS

Experience from Neath Port Talbot and similar surveys led us to believe that (in a UK context at any rate) building era could be determined by eye; that is a Victorian building is visually distinguishable from interwar housing and from 1960's and 70's housing. As illustrated in figure 2, architectural and planning "styles" provide convenient visual clues for identification. Development in the UK has followed certain broad patterns that allow for the identification of buildings by their plan form. For example, housing built prior to WWI is distinguishable by the back-wing form – a main building with rear extension, usually containing the kitchen and scullery. In the inter-war period, a defining feature was the rise in popularity of the semi-detached home. Not only did this form provide rear access without the need for back lanes (Edwards 1981), but they also provided a feeling of space and openness in reaction against bye-law housing. Housing from this later period also often shows a degree of uniformity, largely due to legislative directions aimed at improving substandard housing (Barrett and Phillips 1987; Colquhoun 1999).

An initial subjective comparison of map data and survey data acquired for the Neath Port Talbot region lead to the hypotheses a) that housing of a common era exhibit common plan forms and b) that these common forms alter with the era of construction. Geometrical analysis of building plan forms should therefore be able to distinguish approximate building age. For example, figure 3 shows typical plan forms of two ages of housing, extracted from the region studied. Although the two forms are similar, the pre-1919 houses exhibit a consistently higher aspect ratio and so should be robustly identifiable. Other similar distinctions were observed between other housing eras.

At the time of this initial investigation, digitally encoded maps were becoming readily available. These contained, in addition to road layout, representations of plot and building footprints in polygon form. Within a GIS system, these map polygons could be identified and geometrically analysed, enabling a potentially automated analysis method. The questions were raised: could this digital information be used to aid in the automatic identification of building age? ; could the qualitative differences in housing eras be quantified?

METHODOLOGY

The concept was tested by devising methods of analysis of digital map data and comparing their ability to identify built age in the region which had previously been manually surveyed in detail. The power of the analysis methods could be tested against samples taken from this database to establish applicability and potential accuracy. The region contains a diverse mix of stock, as shown in table 1, and so should provide a reasonable indication of overall identification power in a UK context.

Two different approaches to map analysis were investigated; 1) Shape: an analysis based on the footprint of the buildings, as described in the preceding section, and 2) Context: an analysis based on information about each building's nearby surroundings, such as distance to road.

Shape based methods

Shape methods quantify the outline of the building footprint as extracted from the map. Apart from rectangles, buildings can rarely be expected to take on classical polygon forms, so methods to encode, compare, and group general polygons are required. Two methods for this have been explored; Raster coding and Vertex coding.

Raster coding

Raster coding involves overlaying an analysis grid to encode the vertices of the polygon. This creates a code "number" for the shape. Similar building shapes should define the same code, and so the code

[1] http://www.berr.gov.uk/whatwedo/energy/statistics/regional/index.html

provides the shape clustering automatically. A relatively coarse grid provides some tolerance to map "errors" e.g. a slightly misplaced vertex.

In the GIS system a fixed grid is overlaid on a normalized (i.e. making the longest length unitary) building plan outline, with the building centered in the grid. Internal GIS functions are used to locate nodes (corners) of the building shape; where a node lies in a grid cell this is marked as occupied otherwise the cell is marked empty. As illustrated in figure 4, the occupied/empty cells are then encoded to form a number; in this case 010001110000100001. The resulting codes can be checked for mirroring and rotations.

Vertex coding

Vertex coding utilises a chain coding approach (as described in Fu 1982) to encode the shape of the building plan outline as a sequence of seqment lengths, where each segment, or wall, denotes a significant change of direction. The GIS system can provide the location of vertices and segment lengths for any selected polygon. The information derived from the outline is the number of segments, the total perimeter length and the chain code of the segments, as illustrated in figure 5. Each code is potentially unique, and further processing is required to group similar chains to form shape clusters. As with the Raster method, the codes are first normalised for longest length before further comparison.

Small differences in form, due perhaps to map drawing errors or insignificant differences in shape, can produce unique chain-codes. A method that produces as many clusters as buildings will be unuseful; the method must group together *similar* shapes. In order to group similar building plan forms, a tolerance to differences must be imposed. Any two normalised outlines (of polygons with the same number of vertices) can be compared vertex to vertex and a difference, or variance, parameter ∇ between any two plan forms can be defined as; $\nabla = \sum_{i=1}^{n} (V_i a - V_i b)^2$, where V is a vertex position for plans a and b with n vertices. In order to allow for rotation and mirroring, ∇ can be minimised for any pair. The variance parameter ∇ is used to aid in the formation of useful (i.e. populated) clusters, by defining a difference tolerance ε∇?such that a cluster contains shapes with a low difference; ∇±ε∇. This is illustrated in figure 6, where the tolerance can be set to distinguish between similar and different shapes; with a tolerance of 4 only the first two candidates cluster with the prototype. In our method, each polygon representing a building in a sample can be tested and either form a new group if it is "close" to no others, or be placed in an existing, closest, group. In a two pass exercise, the members of each group are then used to form an average or "prototype" for the group, and the whole population once again tested against these prototypes to form the final clusters of plan shapes.

In these methods, the quality of the grouping will obviously vary considerably according to the parameters used; for instance in the raster method, with the grid size, or in the vertex method, the difference tolerance. In the extremes, two obvious degenerate results exist; each building is in a unique group (tolerance too low) or all buildings are in one group (tolerance too high). A useful result will be a moderate number of groups, with each group containing a large number, and only a few unique (or solo member) groups.

The testing of these shape methods will focus on two questions; can useful (e.g. highly populated) clusters be formed, and once formed, can those clusters inform of built age?

Context based method

The built form reflects the complex political, economic, social, and cultural processes in place at the time of construction, and these processes, of course, change with time. Another approach to establishing built age from map data is therefore to move the focus from the footprint to the building's surroundings; its context.

As with footprint shape, the history of housing development leads to identifiable patterns in the characteristics of the building's relationship to its surroundings. Early 20th century housing favoured the terrace, while later construction is almost exclusively detached or semi-detached homes. These are reflected in the geometrical nature of the property on which the building is placed (the plot) and in the distances between neighbouring buildings. Barr and Barnsley (2004), for instance, used maps to infer urban land use and successfully identified areas with similar built ages by considering street layout patterns. Our intent is to extend this type of analysis to identify the age of individual properties, which may or may not be of similar age to the surrounding development.

For our context analysis, factors were derived based on:- from past experience; their subjective correlation with the built age; the results of a built morphology review; and, mainly for pre-war and inter-war housing, an existing literature. Only indicators that could be readily obtained through geometrical analysis of digital maps were considered. We have devised five such building form indicators:

1. *Plot size*; the total area of the land associated with the building;
2. *Distance to road*; the length from the building main entrance to the nearest roadway;
3. *Road angle*; the angle made from the building frontage to the nearest roadway;
4. *Number linked to*; the number of other buildings directly touching the target

building, for instance a detached house has a link of 0, while a semi-detached has a value of 1 and a mid-terrace a value of 2;

5. *Terrace length*; the total number of buildings that are directly or indirectly linked to the target.

These five parameters were derived for all buildings in the sample, via the GIS system. That data was then used to form a multinomial logistic regression against built age, using the software SPSS. If statistically significant relationships are observed, then age can be inferred from the context form.

RESULTS

Our development and testing of the methods was based on the Ordnance Survey's MasterMap™ product, which has a layer of polygon data that is grouped as regions or objects. These objects have many items of data associated with them; two such items are the "Descriptive Group" and the "Descriptive Term". These two describe layers of 1) buildings, 2) roads and paths and 3) plots within which the buildings sit. For analysis, these maps are embedded within a GIS system; Mapinfo™ in our case. Each of the three methods described above were implemented in Mapbasic™, and tested against purposefully selected samples of the Neath Port Talbot survey area, with each sample containing several thousands of dwellings. The samples could not be completely randomised as: a) we wanted a wide range of ages to be represented in each, and b) the context method requires contiguous areas rather than individual buildings.

Raster coding

As expected, grid density had a significant impact on this method's ability to form useful (e.g. highly populated) clusters. Grids of 6x3, 8x4, and 8x8 were examined, and of these the 8x4 grid produced the best results. Success rates dropped considerably for the others; the grid was either too coarse to delineate difference in shape, or conversely too detailed so that unimportant or erroneous details were included in the codes being generated.

The 8x4 grid produced 491 clusters from a sample of 2000 dwellings. However many of these were "solo" forms; that is the cluster contained only one building. Excluding those, 132 populated clusters were discovered by the method; of the 132, 83 clusters contained a unique building era, while the others contained a mix of eras. Sample plan form "clusters" resulting from this analysis are shown in figure 7. The best agreement (table 2) was found for pre-1919 housing; in this era 69% of the stock in the sample was attributed to unique plan forms (that is, forms not associated with other eras). There were similar clusters found for other ages but success rates were lower; for instance 36% of post-1980 housing and 26% of 1945-1965 housing were correctly identified, however only 12% of 1965-1980 housing were attributable to unique plan forms by this method.

Vertex coding

A more detailed inspection of the map polygons revealed a number of challenges to implementation of this method. Not all buildings were drawn consistently or accurately; for instance extra, redundant, nodes were often placed within a line segment. While this would not affect the original intended use of these maps, they could affect our analyses. Many of these issues were resolved by introducing a tolerance factor; nodes that were within a smallest significance distance (e.g. 0.5m) from another, or represented an angular change of less than 15 degree, were ignored. This would lead to the loss of small details in built form, but this was not considered a significant loss for our purposes.

In a sample of 7144 buildings, 2471 clusters of 2 or more buildings were created, of these 55 were "large" clusters (of 10 or more members). 1390 "solo" clusters were found.

Although the number of clusters produced were high, as shown in table 2 there is an improvement in the identification rates of crucial building eras; pre-1919, and 1919-1945, over the raster coding approach.

Context coding

Implementation of this method showed that the derivation of some of our indicators from the existing map data were problematic. For example, as building frontages or entrances were not explicitly identified in the map data or objects, the frontage of a building could only be inferred to be that closest to the nearest road.

Determining, from the map data, plot area for a property also proved less than obvious. For instance, within the map, a front and back garden of a terrace property may be stored as two polygons objects. In addition, a plot of land may touch more that one property, so that it may appear to "belong" to more than one building. In our analysis, property plots were defined as any land plot attached to the building in question. This simplification results in a proxy for urban density, but may lead to double counting in certain circumstances. In these cases, errors in analysis may be introduced by our assumptions or definitions.

The statistical analysis of the five parameters previously described, using a sample of 7000 dwellings, showed that the best-fit model could correctly classify over 76% of built form over all eras. The pseudo-R statistics, used to determine the proportion of variation explained by the regression model, are 0.636 for the Cox and Snell statistic and 0.696 for the Nagelkerke statistic; these indicate that the regression model was fairly good in accounting for the differences in classification.

As with the other methods, the pre-1919 era buildings showed a high success rate for identification, however the Context method was also very successful in identifying the 1945-1965 era, with a 95% success rate for those properties. However, the classification accuracy of other age periods varied significantly (see table 2). The identification of modern era housing was notable; only 1% was considered by this method to have unique forms. In fact, most modern dwellings were placed erroneously into the 1945-1964 era.

Depending on the age of the building, certain of our indicators were found to be more important than others. For example, for homes built before 1919, the distance to road (sig. 0.001) was one of the most significant indicators, presumably because pre-war terraces were almost uniformly sited very close to or on the front property line. In other age groups, most notably homes built after 1965, there is too much variation in this descriptor for it to be statistically significant.

DISCUSSION OF RESULTS

Table 2 compares the ability of the various methods to resolve building age within the samples tested.

We feel that the results indicate that the analysis methods are capable of analysing digital map data and producing indicators of building age. Building plan forms do cluster and there are correlations with age. However we do not consider the methods sufficiently accurate for general use; further testing and development is required. Of those methods tested, the Vertex code method and the Context method appear to be the most promising for further development.

Identification of pre-1919 housing appears to be relatively straightforward, as both the shape and the context methods were capable of producing identification rates over 90% for this era. This is considered highly encouraging as this era marks a crucial housing type often characterised by solid wall constructions, and a correspondingly poor energy performance; the "hard to heat" home.

On the other hand, the following era; 1919-1945, also typically shows relatively poor energy efficiency, yet the methods have been less successful in identifying buildings in that era. The Context method appears to be more powerful in identifying that era, yet is less powerful that the Vertex method in others. There would therefore appear to be benefit in combining the two methods. At the time of writing, the two methods were implemented and tested independently of each other, and we are now exploring methods to couple the context and vertex approaches.

Mapping and inspection of properties that were mis-identified by the methods has provided several interesting results. Firstly, it appears that in a number of cases the models were actually correctly identifying the built age; it was the initial manual survey that was erroneous and a second visit prompted by this finding showed many anomalies. Secondly, mis-identified properties were often placed only one era off. For example, if the most current eras are combined into one category spanning 1965 to the present, the identification success rate is over 90%. However, such a wide age band would not be useful in determining thermal properties of the buildings. Given the often gradual transition in building construction styles, this uncertainty in identification is understandable, but it implies that there will be a maximum accuracy to which built age can be expected to be identified by an automatic analysis.

Calculations made using a simple error propagation model suggests that, in a population of buildings with a spread of age characteristics representative of the UK, the accuracy of the estimate of the total energy use of the population can withstand even significant errors in age identification. Since the average energy requirements of different building ages are relatively similar (e.g., from table 1, pre-1919 = 39.5 MWh/year, compared to post 1980 = 25.8 MWh/year), and since the total number of properties is accurately known (so that an error in identification places a property in another era), even 30% uncertainty in identification leads to only 3% uncertainty in the total regional energy use.

A more demanding, and potentially more interesting, use of this data/model is to estimate the energy savings accruing from an initiative or investment; for instance, grants to improve the uptake of cavity wall insulation. An acceptable prediction of energy savings over the region (±10% for instance[2]), would, for our test region, require an accurate (to 90%) estimate of pre-1919 stock (in order to remove them from the calculation) and of 1945-1964 stock (as the most prevalent poorly performing era). The other, more efficient stock has less impact on the results, so that even identification accuracies as low as 30% for those eras has little effect. This leads us to believe that we are approaching a useful method, in particular if we can combine the two approaches and successfully identify the eras from pe-1919 through to 1945-1964.

We have yet to test these methods on the full data set of 55,000 dwellings to establish ultimate accuracy for the region. In general, the initial implementations of the methods in MapBasic were notably inefficient and could require days for analysis of the samples used here. Recent improvements of the algorithms and coding used have considerably improved performance; calculation times are now in the order of minutes, and so full regional analyses are now being undertaken.

We now consider it unlikely that any method will be able to fully identify the age of buildings in a region; there will be an upper limit of the accuracy of

[2] Note that this accuracy refers to that resulting from the identification of stock only, not to the accuracy of the underlying energy model.

identification. Changes in built "style" are notable but gradual, and so there will naturally be many properties that appear "out of time" as they straddle the eras. The digital maps that form the basis for the methods are not error free, and even the labour intensive "walk-by" method introduced notable errors in identification. It is likely therefore that each property can only have an age probability determined by any such analysis, providing an age probability distribution (for illustration, for a particular property, a 2% chance it is pre-1919; 4% 1919-1945; 75% 1945-1964; 19% 1965-1980; and 1% post 1980). Calculation methods for regional building energy use should be adapted to recognise such uncertainty in classification, and to propagate these uncertainties to the final energy result. Once implemented however, such a statistical approach would also allow uncertainty to be placed on other parameters, for instance probabilities for retrofit double-glazing, conservatories, or loft rooms could be attached to each era. In order to use and present this information, we consider that the EEP model, for instance, must become more stochastically based, as opposed to the deterministic approach used at present. This avenue is currently being explored.

Finally, when the analyses were undertaken, many interesting anomalies occurred in the results, particularly in the context method. On inspection, these anomalies in context were related to mapping errors (for instance unclosed polygons). This leads us to believe that the techniques developed here may also have a more general utility in discovering mapping errors during the construction or revision of urban maps.

CONCLUSIONS

A number of potential methods for the automated analysis of digital maps have been tested. It has been shown that building age, at least in terms of era, can be inferred from a geometrical analysis of footprint shape or building context. However, while pre-1919 housing can be readily identified, with accuracies greater than 90%, other equally important eras are less well identified. The results are considered encouraging, but further development and combination of the recognition methods is required to bring the overall accuracy up to a generally useful level. In particular, further development is required to combine the two most promising approaches.

Results so far are specific to the region studied; while the authors believe the region studied is not atypical of British suburban housing, we make no suggestion that the predictive models so far generated will work with other countries, or indeed other towns. In application to a "new" region, the models will need to be constructed. It is expected that reasonable accuracy will be attained by "training" the system on a sample of the population to be modelled; while this sample must be manually surveyed to determine the building stock characteristics (age, construction type etc.), the size of the sample should be such that the effort required is significantly reduced, so that the modelling effort becomes more attractive and economic. If a region can be satisfactorily described by a sample of, for illustration 20%, this implies a significant reduction in time and effort required for the survey; 3-4 man-months investment rather than 18.

An automatic age identification method, even if not perfect, will allow a much more efficient survey method, where manual inspection can be targeted to areas or specific buildings where uncertainty exists.

It is likely that there will be an upper limit of the accuracy of identification of built age; even the database produced by a manual "walk-by" method has been found to contain significant errors in identification. This lead us to believe that the next generation of regional models such as EEP must embrace this uncertainty and include it in its calculations, leading to a more stochastic, rather than deterministic, energy calculation methodology.

ACKNOWLEDGEMENT

This work, and the initial development of the original Energy and Environment Prediction (EEP) model, has been funded by the Engineering and Physical Sciences Research Council. The authors thank Neath Port Talbot Borough Council for their support.

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Building era	*Region component*	*Average type fuel use MWh/year*
Pre 1919	35%	39.5
1919 – 1944	13%	38.1
1945 – 1964	27%	29.9
1965 – 1980	18%	32.1
Post 1980	7%	25.8

Table 1 : Stock profile of the Neath Port Talbot survey region; 55,000 dwellings in total.

	Method:		
Building era:	Raster	Vertex	Context
Pre 1919	69%	94%	93%
1919 – 1944	28%	70%	32%
1945 – 1964	26%	20%	95%
1965 – 1980	12%	66%	19%
Post 1980	36%	55%	1%

Table 2 : Proportion of successful age identification for each method.

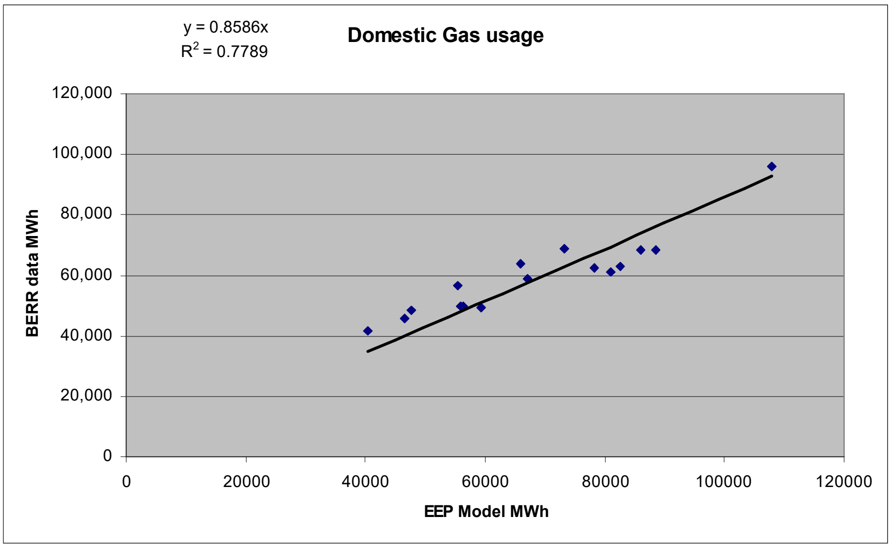
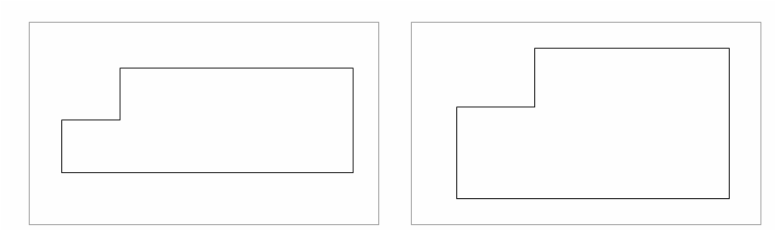


Figure 1: Comparison of regional energy model and actual fuel use.

Figure 2 Two eras in terrace housing.



a) Pre 1919 housing b) 1919 to 1945 housing

Figure 3: Typical dwelling outline patterns.

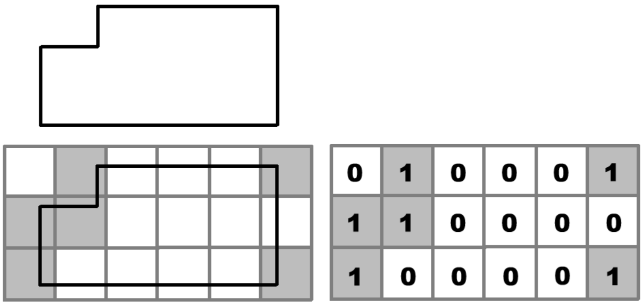


Figure 4: 6x3 raster coding for a building outline.

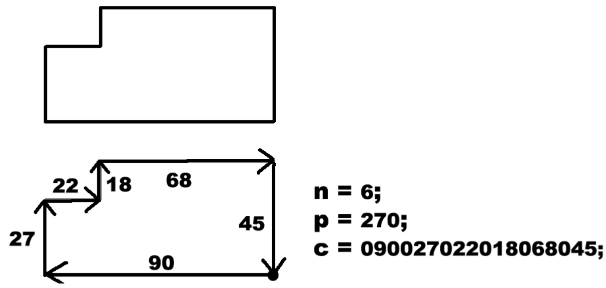


Figure 5. Vertex coding, in dm, for a building outline.

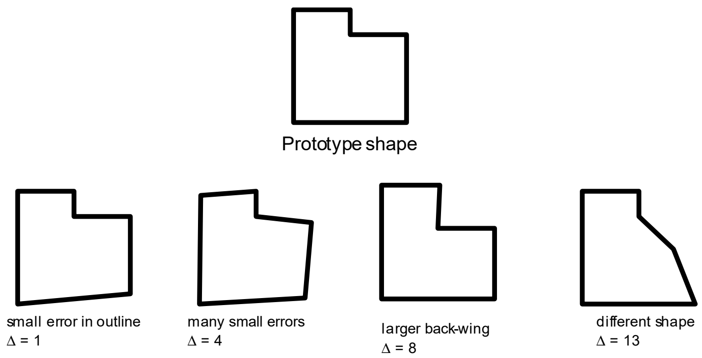
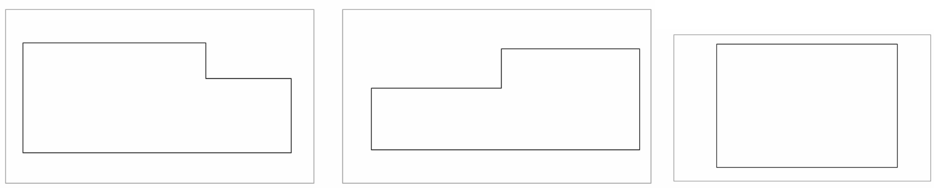


Figure 6. Differences in Difference factor Δ between similar plan forms.



a) b) c)

Figure 7. Example plan forms generated by the raster method; a and b uniquely define an era, while c) covers a number of eras.

Paper 4 - Energy optimisation modelling for urban scale master planning

Jones, P. J., Lannon, S. C. and Rosenthal, H. 2009. Energy optimisation modelling for urban scale master planning. Presented at: 45th ISOCARP Congress 2009: Low Carbon Cities, Porto, Portugal, 18-22 October 2009.

My Contribution in this paper

The research aim investigated in this paper was the challenge of creating the input data to simulate a new urban scale project anywhere in the world. After a review of the contemporary literature I created a research programme to explore the clustering of similar buildings combined with detailed simulation of cooling loads.

In this paper my contribution was the creation of the site input data from the information provided by the client, the simulation of the 7,200 runs and the compilation of results at both building and plot level. In particular I developed new techniques to characterise the overshadowing to analyse the urban scale modelling allowing the clustering of the plots into groups. Coding was undertaken for each plot with two variables, one for the plot form and the other for the obstruction type viewed by the side of the plot. The clustering allowed the plots to be reduced from 1,131 to 80 plot form types and 83 obstruction types.

The development of simulation control was undertaken using text replacement scripts using simple text editing software to replace certain text within the input files of HTB2 to produce the variations required. The work I undertook provided the breakthrough required to manage the complex data structures need for HTB2 simulation at an urban scale.

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To whom it may concern,

Regarding the paper:
Jones, P. J., Lannon, S. C. and Rosenthal, H. 2009. Energy optimisation modelling for urban scale master planning. Presented at: 45th ISOCARP Congress 2009: Low Carbon Cities, Porto, Portugal, 18-22 October 2009.

I worked with Simon on the EPSRC funded projects related to the Development of the EEP model this paper is a result of the research undertaken. In this paper Simon's contribution was the creation of the site input data from the information provided by the client, the simulation of the 7,200 runs and the compilation of results at both building and plot level. In particular new techniques were produced to characterise the overshadowing to analyse the urban scale modelling allowing the clustering of the plots into groups. Coding was undertaken for each plot with two variables, one for the plot form and the other for the obstruction type viewed by the side of the plot. The clustering allowed the plots to be reduced from 1,131 to 80 plot form types and 83 obstruction types. The development of simulation control - was undertaken using text replacement scripts using simple text editing software to replace certain text within the input files of HTB2 to produce the variations required.

If you have any questions regarding this matter please do not hesitate to contact me.

Yours sincerely,

Prof Phil Jones

Energy Optimisation Modelling for Urban Scale Master Planning

Introduction

Gateway City is a major city development in the emirate of Ras Al Khaimah (RAK) of the United Arab Emirates (UAE). The development covers a site area of over 1,100 ha. comprising an integrated city designed to service, support and supplement the capital city of Ras Al Khaimah. Master Planning and Urban Design for this project was carried out by ACLA Ltd, part of the Hyder Consultancy group. Cardiff University was appointed to carry out an Energy Optimization Study of the master plan layout.

The aim of the study was to analyse the overall impact of building structure related energy efficiency measures and to identify potential energy savings at an early master planning stage that could feed into subsequent planning and design stages. The objectives of the study were as follows:

- To identify energy performance of base case requirements utilizing current and existing standards appropriate for RAK and the UAE.
- To develop options for optimizing energy performance and to identify variations due to orientation, over-shadowing, and buildings of different height, internal gains and construction type (in relation to thermal performance).
- To explore how this information, which is at a city scale, can be automated to provide guidance for individual plot planning.

Figure 1 Plots by building types

For the purposes of energy modelling, buildings were categorised into commercial, residential and institutional types of uses. Figure 1 presents a plan of the development identifying each plot in terms of its building type. The additional ‘mixed use’ category is where two or more of the categories are within one plot. The utility category has not been included in the analysis at this stage.

Methodology

The data used in this study was derived from the Gateway City Detailed Master Plan Plot Schedule, as supplied by Hyder-ACLA Ltd (HK). This comprehensive source provided the following data per plot, from which cooling loads were modelled: plot number; land area; (m2); land use; building height (max. number of storeys); building heights for each plot; gross floor area by type of building; car parking area.

The impacts of different building height, orientation, over-shadowing, fabric, and levels of power usage on cooling load were examined. To predict the cooling load and thermal performance of a building the thermal and energy computer simulation model HTB2 (Alexander, 1996) was used. HTB2 is a widely used and tested simulation tool, for example, it is used in the Hong Kong Environmental Assessment Method, HK-BEAM (Burnett et al., 1997). In this study HTB2 has been linked with the Energy and Environmental Prediction tool, EEP, which is an urban master-planning model (Jones et al., 2000). EEP was originally developed for predicting energy demand at an urban scale for existing buildings and has now been modified to consider new urban scale developments.

In this study it has been assumed that the building cooling loads are met by a district cooling system. A number of aspects of the impact of building variants were investigated for all the variants, comprising: 8 orientations, 3 over-shadowing variants open normal and dense, 2 occupancy and internal gain patterns for each of commercial, residential and institutional, 5 fabric specifications from standard to low energy, and10 building heights from single storey to 19 storeys. The various combinations of these variations resulted in 7,200 simulation runs, each for a full year at a 20 second time step.

Results & Discussion

This study has identified the potential for energy savings at an early master planning stage. The following factors were considered in relation to the cooling load, with information on the variations presented in tables 1 to 3:

- Building orientation (façade facing 8 different directions);
- Over-shadowing by neighbouring buildings (Table 1);
- Construction performance in relation to levels of thermal insulation and glazing type (Table 2); and
- Internal heat gains from lighting, small power, etc (Table 3).

The first two factors relate to the performance of the building in relation to its position within a plot, that is, which direction a facade faces and its closeness to adjacent buildings. The last two factors are building specific and are not affected by location within the plot.

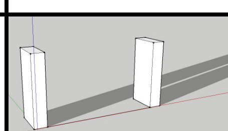
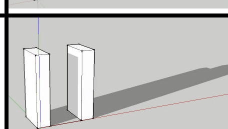
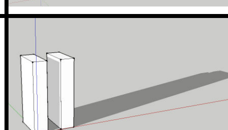
Table 1 Over-shadowing	Visual representation	Variant
Open 18 storey (54m) obstruction 100m away		**1**
Normal 18 storey (54m) obstruction 40m away		**2**
Dense 18 storey (54m) obstruction 20m away		**3**

Table 2 Construction Type	Fabric values	Variant
Standard Walls Glazing Solar heat gain coefficient	0.4 W/m2.K Double glazing (SHGC) 0.23	1
Standard with enhanced fabric Walls Glazing Solar heat gain coefficient	0.2 W/m2.K Double glazing (SHGC) 0.23	2
Standard with triple glazing Walls Glazing Solar heat gain coefficient	0.4 W/m2.K Triple glazing (SHGC) 0.23	3
Standard with Solar control Walls Glazing Solar heat gain coefficient	0.4 W/m2.K Double glazing (SHGC) 0.15	4
Low energy Walls Glazing Solar heat gain coefficient	0.2 W/m2.K Triple glazing (SHGC) 0.15	5

Table 3 Building type	Heat gains Low / High	Occupancy	Variant
Residential Low power usage	20 / 50W/m^2	00:00 – 09:00 & 17:00 - 24:00 Mon to Fri 00:00 – 24:00 Sat to Sun	**1 / 4**
Commercial Low power usage	30 / 50 W/m^2	07:00 - 18:00 Mon to Sat	**2 / 5**
Institutional Low power usage	25 / 50 W/m^2	07:00 - 18:00 Mon to Fri	**3 / 6**

Results for the potential range of cooling load reductions are summarised in the radar plots in Figures 2 to 4 for residential, commercial and institutional buildings respectively. They indicate the range of savings in relation to individual façade performance, taking account of overshadowing and orientation. The largest potential energy savings are from reducing internal gains, which includes, for example, the reduction in power used for lighting as well as the cooling load associated with lighting heat gains. The other potential savings for orientation, overshadowing and construction type are of the order of 20% on a façade based performance approach. Of course when combinations of energy saving measures are considered the savings will not be additive.

Results for variations in building height, orientation

The cooling load was calculated for each of the eight orientations for a 19 storey sample building, showing variation of cooling load with storey height and orientation. Example results are displayed in figure 5 for a residential building in the form of a radar plot for minimum over-shadowing by adjacent buildings (variant 3). It shows that changes in façade orientation can give rise to increases in cooling load of typically up to 20 to 23% with southwest facing facades having the largest cooling load and north facing facades the lowest. This indicates that where possible the main glazed facades of buildings should be oriented to face north (or north east, north west).

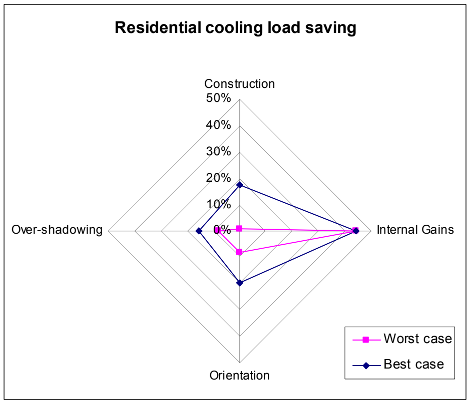


Figure 2 Residential cooling load savings

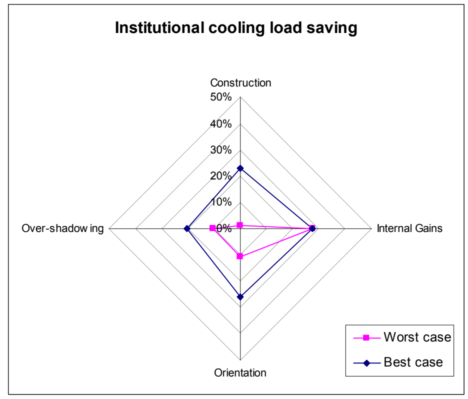


Figure 3 Institutional cooling load savings

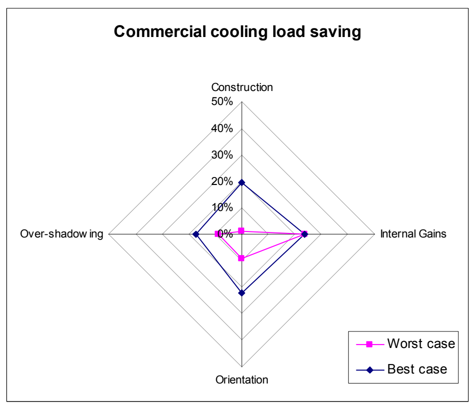


Figure 4 Commercial cooling load savings

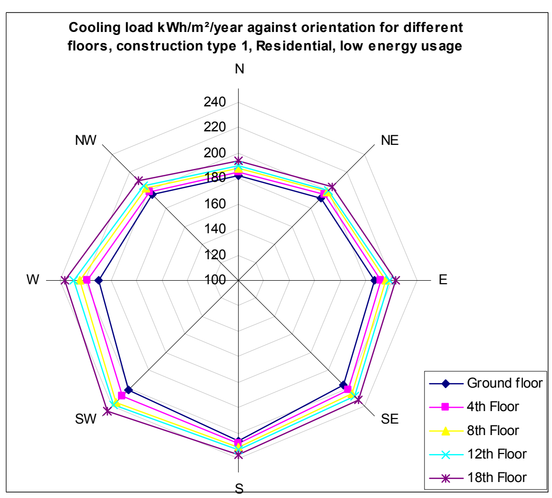


Figure 5 Residential building cooling load (kWh/m²/year) against storey

Results for variations in over-shadowing and orientation

Figure 6 presents the results for a residential building for variations in orientation and overshadowing (construction variant 1 and internal gains variant 1). The difference between the overshadowing variants varies according to orientation. Overshadowing of buildings by adjacent buildings can reduce cooling loads by up to 15 to 17% for southwest facing buildings and typically 5 to 8% for north facing facades. It is therefore recommended that where possible buildings are situated close to each other to provide shading of the facades.

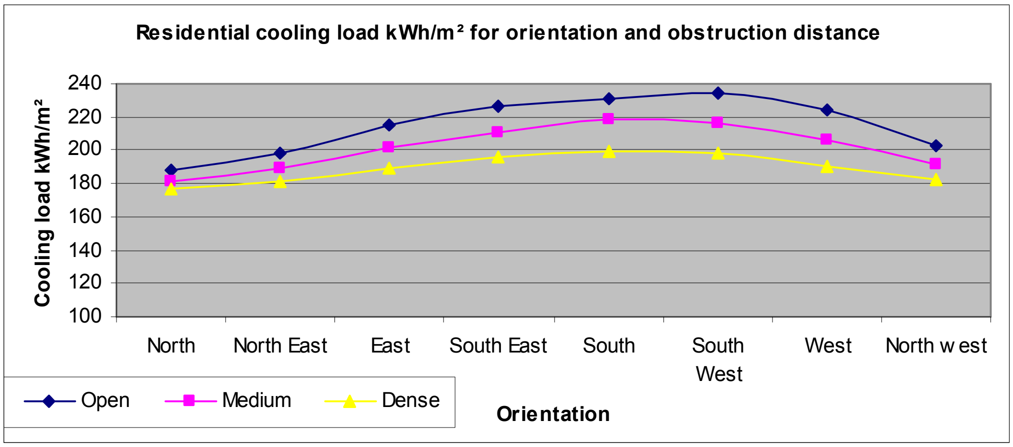


Figure 6 Cooling load versus orientation for different variants in over-shadowing

Results for different levels of internal gains and construction type

Reducing the internal power load from 50 W/m2 (high gains) to 20 to 30W/m2 (low gain) was shown to reduce cooling load by 46%, 26% and 30% for residential, commercial and institutional buildings respectively. The application of energy saving measures to the building fabric can reduce annual cooling loads by 7% to 14%,, 12% to 16% and 13% to 20% for residential, commercial and institutional buildings respectively for high to low internal power gains (Figure 7 shows results for low internal power gains). The combination of low internal power gains and energy saving fabric measures can reduce cooling loads by between 38 to 54%. In addition to the reduced cooling load, the reduction in internal power gains will also lead to considerable power savings due to the reduced direct power used by lighting, etc.

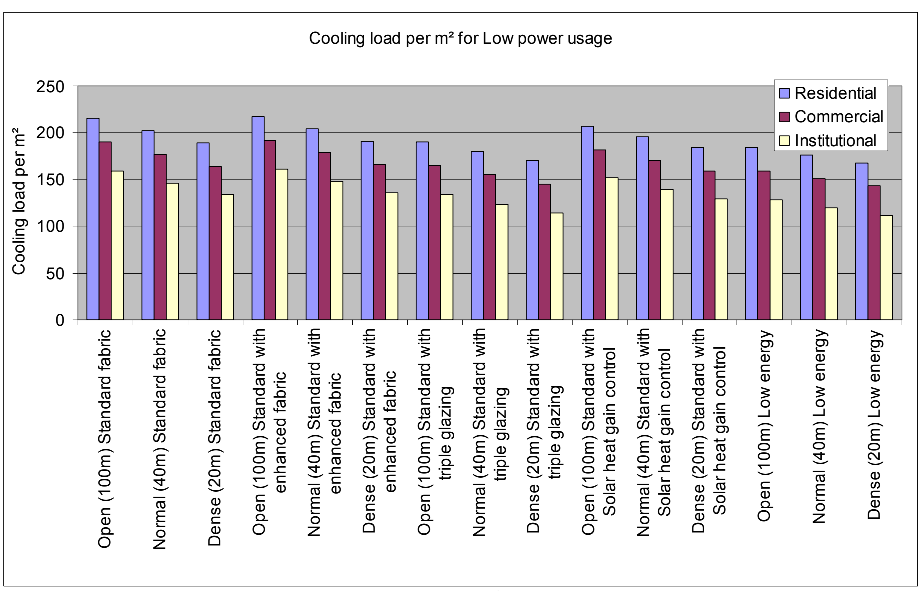


Figure 7 Cooling load per m^2 for High power usage

Summary of cooling load reductions

The potential cooling load reductions are summarised in Figure 8. They show the potential reductions for the factors considered, that is, building orientation, over-shadowing, construction thermal performance and internal load heat gains. The orientation and overshadowing are related to individual façade performance, so a whole building performance will need to take account of all facades. The building designs will include combinations of these four factors. However it should be noted that they are not additive and final cooling loads will be less than the sum of the individual potential load savings.

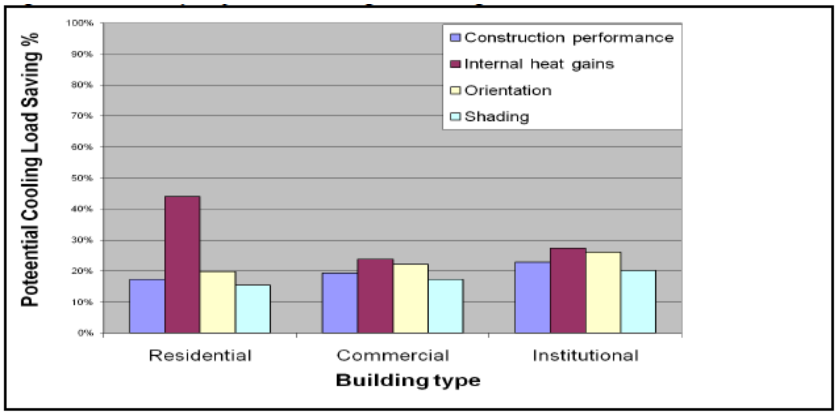


Figure 8 Summary of potential cooling load savings

Plot Development Controls

The analysis described above provides general early master-planning design guidelines for reducing energy demand and estimating the overall carbon footprint of the development. Following this, specific guidance for individual plots can be produced during the concept design stage using the same modelling techniques.

The aim of this plot guidance is to provide a simple procedure to reduce the cooling load of individual buildings on a plot in the master plan. Exploratory work was carried out based upon a typical plot map (Figure 9). The impact of a specific building design, for example, the red building in figure 9a on cooling load has been predicted for variations in orientation and overshadowing as indicated in figure 9b. . Figure 9b shows the relative building height, where h is the height of the chosen (red building) and the distance between the buildings is shown in metres. Where the building is marked “0h” this is direction is treated as 100m overshadowing or ‘nearly unobstructed’.

(a) (b)

Figure 9 3D view and plan of example plot

The procedure created is based around a cooling load radar diagram. For example Figure 10 shows results for the residential buildings. The radar plot is cooling load (kWh/year/m²) for each façade. The building lies on a north-east south-west axis and the circles represent the façade performance for the four facades of the building. The façade length to perimeter ratio is then used for each façade to produce a cooling load for the building in this case it is the average of the four values 185 kWh/year/m^2 of façade area.

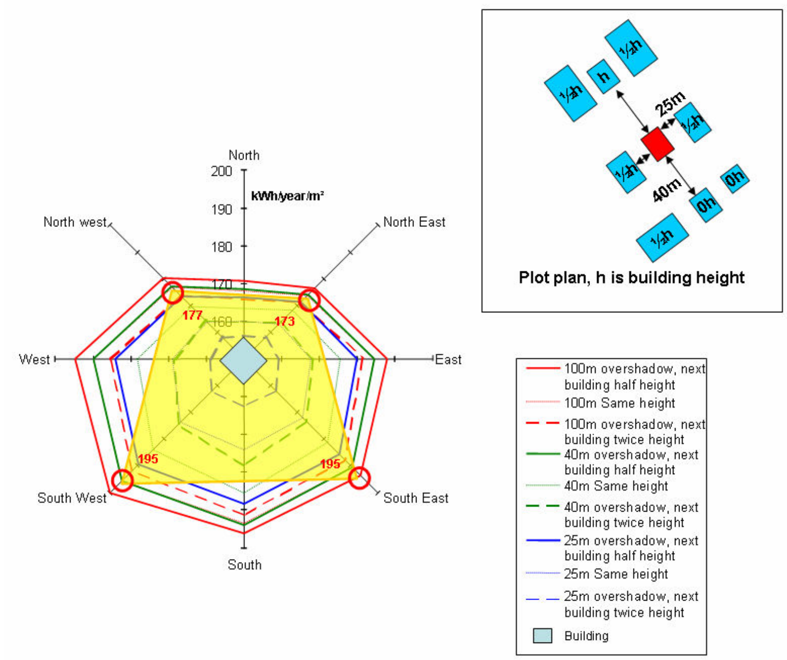


Figure 10 Example plot radar diagram cooling load in kWh/year/m^2

Conclusions

Energy optimisation modelling can provide considerable energy savings if applied at an early master planning stage.

The largest potential energy savings are from reducing internal gains, which includes, for example, the reduction in power used for lighting as well as the cooling load associated with lighting heat gains. The combination of low internal power gains and energy saving fabric measures can reduce cooling loads by between 38 to 54%.

The other potential savings for orientation, overshadowing and construction type are of the order of 20% on a façade based performance approach. However when averaging across all facades the total savings will be less.

It is recommended that all factors are considered at early stage master planning and that they are included in the brief for developers to incorporate in their designs. As the project advances it is recommended that more detailed predictions be carried out to expand the design guidelines for developers

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Jones P, Williams JL and Lannon S (2000), Planning for a Sustainable City: an Energy and Environmental Prediction Model, Journal of Environmental Planning and Management.

Phil Jones, Welsh School of Architecture, Cardiff University
Simon Lannon, Welsh School of Architecture, Cardiff University
Hendrik Rosenthall, Hyder Consultants

Paper 5 - Calculating the solar potential of the urban fabric with SketchUp and HTB2

Bassett, T. Lannon, S., Elsayed, M., Waldron, D., Jones, P. 2012. Calculating the solar potential of the urban fabric with SketchUp and HTB2. Presented at: Solar Building Skins, Bressanone, Italy, 6-7 December 2012.

My Contribution in this paper

This research was undertaken as part of the Low Carbon Built Environment project, and as work package leader I created the aims to develop the work undertaken in Paper 4 into a coherent tool. In addition to setting the aims of the project I reviewed the literature in detail and I contributed to the complex coding required to develop the tool.

My contribution to this paper was the scripting work that I along with Mahmoud Elsayed undertook to create the shading and reflection masks. The VirVil plugin allows access to the internal data within SketchUp. I extracted this information into a series of Microsoft Excel spreadsheets to provide a simple results file for the extraction of element information to construct embodied energy calculations and renewable energy potential assessments.

The work I undertook formed the first step to a tool that combines complex simulation and the large data requirements needed to model at an urban scale.

19 September 2014

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To Whom It May Concern:

In 2012 I attended the 7th annual Solar Building Skins conference in Bressanone, IT, to present a sample of the work our research team were conducting at the time into urban scale energy modeling (Bassett, T., *et. al. Calculating the solar potential of the urban fabric with SketchUp and HTB2.*) The paper was a joint-authorship between myself (lead), Simon Lannon, Diana Waldron, and Mahmoud ElSayed, with the head of LCRI Prof Phil Jones also on the paper.

I understand Simon Lannon is pursuing a PhD by publication, and I wish him every success. His work during my three-year research post at the WSA was instrumental to our team and contributed directly to the successes I enjoyed as a researcher and from which I continue to benefit as an employee at BRE. He has written a summary of his contributions to this specific paper, which I include here:

"My contribution to this paper was the scripting work that I along with Mahmoud ElSayad undertook to create the shading and reflection masks. The VirVil plugin allows access to the internal data within SketchUp. The work I undertook extracted this information into a series of Microsoft Excel spreadsheets to provide a simple results file for the extraction of element information to construct embodied energy calculations and renewable energy potential assessments."

I fully agree with this statement, and I continue to be grateful to Simon for his work on this paper.

Sincerely,

Tom Bassett

Calculating the solar potential of the urban fabric with SketchUp and HTB2

Thomas Bassett, Simon Lannon, Mahmoud Elsayed,
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Abstract

This paper introduces a new tool for analysing annual solar insolation potentials for façades and roofs at an urban scale using Trimble SketchUp and the dynamic simulation model HTB2. The tool is in the form of a plug-in which 1) generates shading masks for every façade and roof in a model, 2) exports geometries to HTB2 for analysis, 3) invokes HTB2 from within SketchUp, and 4) returns outputs into SketchUp for review. It is demonstrated its capability to calculate the effects of complex terrain (imported from Google Earth) on façade and roof solar insolation levels. Case studies of the tool, applied to both urban and rural areas of Wales and Europe, are examined and results discussed. The simplicity of the tool in performing complex solar potential analyses is demonstrated, and its broader application as an analysis tool for calculating urban energy demands are presented.

1. Introduction

As part of the Low Carbon Research Institute's work on energy supply and demand on an urban scale, we have developed a tool to calculate the solar potential of all urban roofs and façades in a model using HTB2 [1] as our thermal calculation engine and Trimble (previously Google) SketchUp [2] as the user interface. This paper is a technical review of the *Virvil for HTB2* plug-in capabilities, reviewing its findings of solar studies performed for urban areas across various regions.

2. Methodology

2.1 Shading Masks

HTB2 uses shading masks generated from each façade and roof to calculate the impact of solar radiation on a building. In order that the plug-in works effectively across an entire model, shading masks need to be generated automatically in SketchUp, and this procedure forms the backbone of the tool. Ray-casting is the basis of the shading mask generator in SketchUp. The centre point of each façade within a SketchUp model serves as the source of rays querying the surrounding urban and extra-urban fabric. Rays are generated at a user-defined angle separation of 10°, 5°, 2°, or 1°, they are infinite in length and invisible to the user to speed up processing times.* The first object hit by a ray in the model is registered as an obstruction in the shading mask for that azimuth and altitude cell. If no object is struck, the cell is registered as unobstructed. For calculations in HTB2, the sky vault is divided into 324 cells (0°-360° azimuth and 0°-90° altitude) [3] and thus user-specified angle separations of less than 10° are aggregated to yield an obstruction percentage for the given cell (0%-100%). Shading masks are saved natively within the SketchUp model for analysis and comparison.

* A separate process within SketchUp allows for the visualisation of the rays and the view of the sky vault from the perspective of the centre point of a given façade, for illustrative purposes.

2.2 Terrain

Figure 1: Imported Alpine terrain as seen in SketchUp

A significant amount of research has worked on the calculation of the effects of terrain solar radiation levels on urban, regional, and national scales using LiDAR, digital terrain model (DTM) and GIS data [5-8]. With the release of SketchUp 8 in 2010, terrain can be imported from Google Earth [9] directly into SketchUp for use in solar calculations (Figure 1). Terrain in Google Earth is generated from digital elevation model (DEM) data gathered by the Space Shuttle Endeavour in 2000 [10, 11]. In cases that structures, towns, or cities are located on hillsides or in deep valleys, the imposition of the terrain on solar access becomes necessary to calculate, and the import from Google Earth simplifies this process. Various existing software address terrain profiles in various ways, either via physical photographs of the site [12], drawings of the horizon profile into a model [13], or modelling terrain manually [14]. With SketchUp, DEM data of local terrain is imported from Google Earth as a component, and the models of a city are built within the terrain. The terrain can then be detected by the ray-casting from each façade when the plug-in is invoked to generate shading masks.

2.3 Reflections

Ray-casting allows for the generation of reflection masks for affected façades. The impact of solar reflection from neighbouring buildings in terms of glare and increased cooling loads can be a significant issue in the urban environment, and it has been discussed widely [15, 16]. The *Virvil for HTB2* plug-in allows for visualisation and calculation of this phenomenon in SketchUp. Using the same ray-casting process to calculate shading masks, the plug-in uses one bounce off an opposing façade. If the reflected ray strikes another object in the model, the cell is registered as obstructed. Otherwise, the reflected angle is aggregated in a reflection mask for the façade, with the angle and altitude of the reflected ray compiled as the cell of the sky which the façade actually 'sees.' The solar radiation received from this cell of the sky is tempered by the angle of incidence and by the reflective properties of the façade which initiated the reflection. This amount of received solar radiation is calculated and compiled with every reflected ray in an additive manner to calculate the effects of reflected radiation onto a façade. Work by Roos, et. al. [17] and the Berkeley National Laboratory [18] has defined reflection properties of glazing at various angles, properties which have been used in the calculations here, and research is on-going to refine these values. The *Virvil for HTB2* plug-in allows for the illustration of the portions of the sky on a façade that actually 'sees' via reflection off neighbouring façades. For instance, Figure 2 illustrates the southwest segment of the sky vault on an east facing façade on a neighbouring building that 'sees' via reflection off the face of the tall skyscraper positioned to the east.

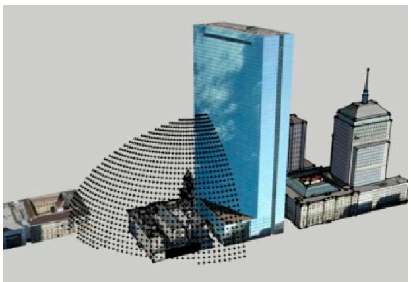

Figure 2: Segment of sky as viewed by a hotel façade in Boston, USA due to skyscraper reflection.

3. Results

As the tool is in its inception phase, several tests and subsequent results are presented here to demonstrate the versatility and accuracy of the tool and its outputs.

3.1 Terrain

Figure 3: Modelled houses without terrain

Obstructions to the sky vault limit the amount of solar radiation received by a façade or roof. In dense urban areas, neighbouring buildings provide the greatest obstructions to a structure's façades or roof, but in areas of aggressive terrain, the surrounding environment can occlude a significant portion of the view of the sky from a façade or roof. In terms of building physics, this can have a detrimental effect on the heating loads for a broad swath of existing and proposed structures. In order to test the percentage of obstruction landscapes can impose, houses in New Tredegar, a village in the Welsh Valleys north of Cardiff in Wales, were modelled. The structures were modelled using photographs, Google StreetView and Google Earth images. Two tests were then run: one leaving the geography flat (as seen by a satellite, for instance) with the modelled houses all resting on the horizontal plane and one by importing the terrain into the model from Google Earth and modifying the positions of the modelled houses to represent reality. Only the houses in the immediate vicinity which would obstruct the view of the sky vault from the tested structures were modelled. The terrain – hills to the southwest and northeast – was an object providing the greatest obstruction. The roofline rotation of the modelled houses was 44.8° west of north, and the roof tilt was 35°. Results are presented in Table 1, and demonstrate a reduction due to terrain in solar insolation for tested roofs to be 10% for the southeast-facing (down valley) roofs, and 25% for the southwest-facing (hill-facing) roofs. This is significant, as many modern calculations by domestic solar companies for solar potential are made using satellite images. If the terrain is not considered, a considerable portion of promised solar radiation will not be delivered. Similar tests can be carried out using the tool for virtually any location on the globe if local climate data is also available.

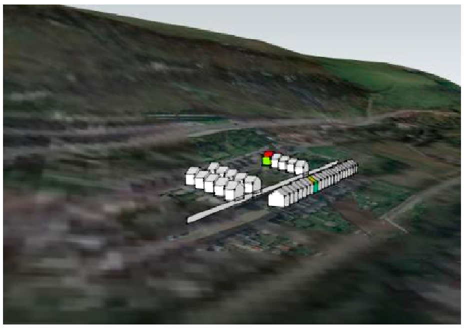

Figure 4: Modelled houses with terrain

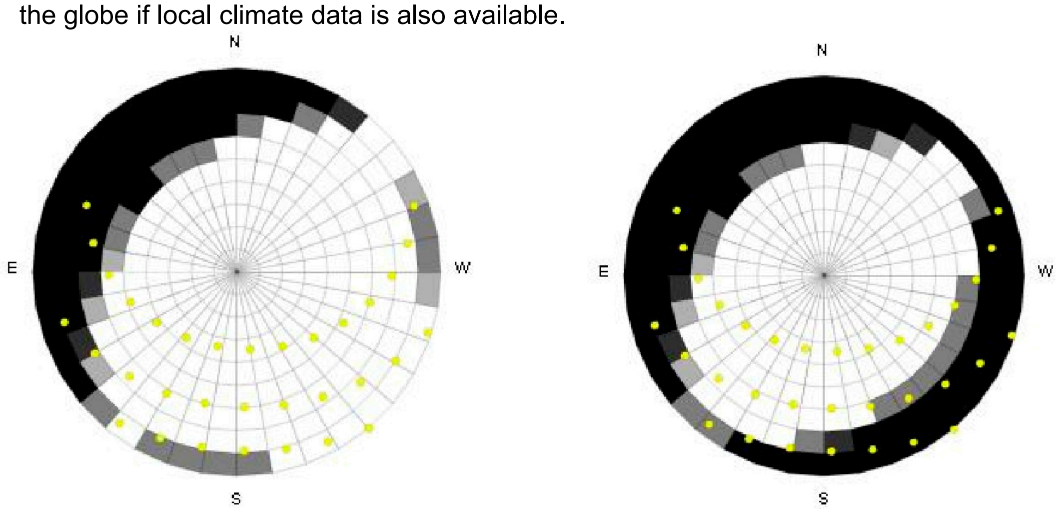

Figure 5: SW-facing roof shading mask showing no terrain (L) and imposition of terrain to the southwest (R)

Table 1: Imposition of terrain on annual solar potential calculations

Roof Orientation	**No Terrain (kWh/m²)**	**With Terrain (kWh/m²)**	**Difference (%)**
South West	1056	847	- 25
South East	1023	932	- 10

3.2 Solar Radiation

In another test of the plug-in, levels of available façade solar radiation in an urban environment were queried on a model in Cardiff, Wales. Streets in a Cardiff neighbourhood were modelled with the assistance of Google StreetView, photographs, Google Building Maker, and Google Earth. Foliage was added to the back gardens by importing 3-D trees into the model from Google's 3D-Warehouse, and chimneys were modelled to maximise accuracy. Tests were run to identify the solar potential of the roofs and façades in an urban environment using a ubiquitous Cardiff house type (terraced properties) and neighbourhood layout, as seen in Figure 6. The results of this test are shown in Table 2, and demonstrate a difference between east- and west- facing roofs of terraced housing in the neighbourhood, compared with a level of solar potential of terraced housing for the south-facing roofs in the neighbourhood. Façades can be divided into smaller faces in SketchUp for a more detailed analysis of solar insolation, as shading masks are generated for each face and can be averaged over the entire façade. The roofs in Cardiff were divided into 8 even faces and the total roof solar insolation results were compared with the previous test. The results can also be seen in Table 2; dips in insolation by 1.4% – 2.9% can be attributed to the chimneys on the houses. A greater division of the roof will analyse the impact of the chimneys in more detail, and the results of this test demonstrate models can be analysed in fine detail using the tool.

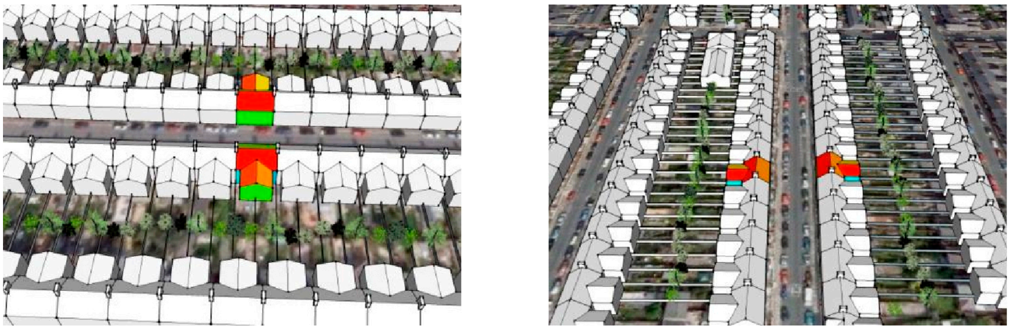

Figure 6: Views of the Cardiff radiation models

Table 2: Solar Radiation Results of divided facades in Cardiff

	Undivided Roof (kWh/m²)	**Divided Roof (kWh/m²)**	**Difference (%)**
South	1038	1023	- 1.4
West	947	927	- 2.2
North	703	683	- 2.9
East	830	810	- 2.5

4. Conclusions

This paper has introduced a new solar calculation tool for use with Trimble SketchUp. The *Virvil for HTB2* plug-in provides a diverse platform for investigating the solar potential of structural skins. Entire neighbourhoods and cities can be modelled according to their basic form, and the creation of shading masks for every façade enables accurate analysis in HTB2. Examples in this paper demonstrated a significant imposition of terrain on solar radiation levels received by existing façades and roofs, as well as the effects surrounding landscaping and urban fabric have on solar potentials. This link between modelled buildings in SketchUp with HTB2 can also provide a suite of building energy performance data, including annual operational energy requirements, heating and cooling demands, and other data relevant to the ongoing energy demands of the urban environment. Future works within the LCRI will refine the reflections calculations and provide faster calculation times.

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Paper 6 - Retrofitting existing housing: how far, how much?

Jones, P. J., Lannon, S. C. and Patterson, J. L. 2013. Retrofitting existing housing: how far, how much?. Building Research and Information 41(5), pp. 532-550. (10.1080/09613218.2013.807064)

My Contribution in this paper

The research presented in this paper required the energy modelling of a large number of dwellings. Based on the literature and the available tools I continued to develop the domestic sub-model used in this paper to answer the research question "How to model buildings at an urban scale?". However in this instance there was a different requirement, I needed to explore the potential retrofit options available including renewable technologies such as PV and heat pumps.

In this paper I used the techniques from Papers 1 and 3 to build input data for modelling the outcomes of retrofit projects. This also allowed the exploration of rapid survey techniques using Google Street View and other available mapping data sources. In addition I improved the modelling of CO_2 emissions reduction by concentrating on the prediction of the fuel mix within the properties.

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6th November 2014

To whom it may concern,

Regarding the paper:
Jones, P. J., Lannon, S. C. and Patterson, J. L. 2013. Retrofitting existing housing: how far, how much?. Building Research and Information 41(5), pp. 532-550. (10.1080/09613218.2013.807064)

I worked with Simon on the EPSRC funded projects related to the Development of the EEP model this paper is a result of the research undertaken. In this paper Simon used the techniques to build data for modelling the outcomes of retrofit projects. This also allowed the exploration of rapid survey techniques using Google Street View and other openly available mapping data sources. The modelling built on the fuel mix calculations to ensure the CO2 improvements were realistic.

If you have any questions regarding this matter please do not hesitate to contact me.

Yours sincerely,

Prof Phil Jones

Paper 7 - A sap sensitivity tool and GIS-based urban scale domestic energy use model

Iorwerth, H., Lannon, S., Waldron, D., Bassett, T. and Jones, P. 2013. A sap sensitivity tool and GIS-based urban scale domestic energy use model. Presented at: Building Simulation 2013 (BS2013): 13th International Conference of the International Building Performance Simulation Association, Chambéry, France, 25-28 August 2013. Proceedings of BS2013: 13th Conference of the International Building Performance Simulation Association. International Building Performance Simulation Association (IBPSA), pp. 452-459.

My Contribution in this paper

This work was part of the Low Carbon Built Environment project, and as work package leader I developed the research aims to develop the earlier work undertaken in Paper 1 and 6 into a retrofit options tool. In addition to setting the aims of the project and reviewing the literature to set the scene, I contributed to the coding required to develop the tool.

My contribution to this paper is the development of the SAP calculation engine for the SAP sensitivity tool. The calculation engine was then extracted and placed in a web interface to allow direct output of the results to the user. This allowed the EEP model to be applied in a more rapid way and to explore the variations in thermostat set point behaviour and other variations.

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31/10/2014

To whom it may concern,

Regarding the paper:

Iorwerth, H., Lannon, S., Waldron, D., Bassett, T and Jones, P 2013. A sap sensitivity tool and GIS-based urban scale domestic energy use model. Presented at: Building Simulation 2013 (BS2013): 13th International Conference of the International Building Performance Simulation Association, Chambéry, France, 25-28 August 2013. Proceedings of BS2013: 13th Conference of the International Building Performance Simulation Association. International Building Performance Simulation Association (IBPSA), pp. 3441-3448.

I worked with Simon on the Low Carbon Built Environment project and this paper is a result of the research undertaken. I can confirm that Simon was responsible for the development of the SAP calculation engine for the SAP sensitivity tool which was fundamental for the development of the model. In addition, the innovation of enabling results to be directly outputted into a web interface allowed variations in model parameters to be explored with ease. The ability to change modelled parameters such as thermostat behaviour rapidly was a significant contribution to one of the paper's major conclusions.

Yours sincerely,

Heledd Iorwerth

A SAP SENSITIVITY TOOL AND GIS-BASED URBAN SCALE DOMESTIC ENERGY USE MODEL

Heledd Iorwerth[1], Simon Lannon[1], Diana Waldron[1], Thomas Bassett[1], Philip Jones[1]
[1]Welsh School of Architecture, Cardiff University, Cardiff

ABSTRACT

This paper introduces a new approach to predicting domestic energy use on an urban scale and is based on a method of applying sets of results from a SAP (UK's Standard Assessment Procedure) sensitivity tool (WSA 2013) to an area, using and extracting data from a Geographical Information System (GIS). It is demonstrated for the Cardiff Local Authority (LA) area (approximately 140,000 dwellings) and is validated by comparison with the Department of Energy and Climate Change's (DECC) data on actual residential gas and electricity consumption per UK census area (DECC 2010). The method concludes by applying results from the validation to modify variables and assumptions in the SAP sensitivity tool in order to better reflect consumption patterns in UK households.

INTRODUCTION

The domestic stock is directly responsible for 27% of the UK's total emissions and it is predicted that ²/₃ of the existing stock will still be standing in 2050 (Forseight 2008). Reducing emissions from existing dwellings is therefore crucial to the success of the UK government's 2050 target to cut greenhouse gas emissions by 80% (DECC 2009). There is also a growing recognition that action by Local Authorities will be critical to the achievement of this target (DECC 2009). National Indicator 186 requires each Local Authority to publish figures on carbon emissions yearly, including emissions from housing (DECC 2009). This is an enormous challenge for Local Authorities due to the lack of consistent publically available tools and methods for calculating the potential carbon savings (Urge-Vorsatz 2007; DECC 2009). This need by local governments is also acknowledged by (V. Cheng 2011) who identifies that current UK models are evaluated at national level and therefore could become speculative on disaggregated levels (e.g. cities, regions and Local Authorities).

Domestic bottom-up models attempt to estimate baseline energy consumption by applying quantitative data to representatives of the housing stock. They are expected to be capable of assessing and identifying suitable measures to reduce energy consumption on a large scale. (Firth 2010) highlights the potential of constructing simpler models with only a set of limited input parameters and associated sensitivity coefficients. Moreover (M. Kavgic 2010) emphasises that the transparency of data sources and model structures is a crucial issue for their future use.

This paper attempts to outline a transparent method based on a simple tool with a limited set of input parameters. It accentuates variables and assumptions with the greatest significance in terms of energy consumption such as total floor area and indoor temperature set point. The accurate identification of dwellings is also fundamental to the method and although specific to this case study, similar methods and data sources could be used for any UK area. It is hoped that the tool's rapidity and its simple transfer to GIS results in a method that can analyse the effect of adjustments to fabric or system parameters on a regional scale. This along with its transparency and flexibility means that, in future, it could be applied to any number of census areas and could easily be used as a prediction tool for energy efficiency and renewable energy technologies for any area in the UK from neighbourhood to national level.

METHOD

Overview of Method

Cardiff Local Authority area was used as a case study, which included around 140,000 dwellings in total covering 214 Census areas, also known as Lower Super Output Areas (LSOA). The method comprised three main steps: the first analysed data sources relating to the identification and classification of dwellings while in the second, the SAP sensitivity tool was used to calculate the baseline energy demand for the identified classifications. This was based on statistical data relating to the prevalence of fabric and system characteristics. Both sets of data were combined and aggregated to LSOA level using a GIS before initial identification, classification and energy demand results were compared with reliable external sources. The final step builds on the discrepancies found when comparing the energy demand of the model with actual energy consumption data on an aggregated level (LSOAs). In line with common limitations and issues of domestic energy models identified by others in the field, a first attempt was made to adjust and refine the model. The adjusted model's result was analysed and used to evaluate its capability and identify further work needed to ensure its reliability when approximating the effect of energy efficiency measures on different scales. An overview of the method can be seen in figure 1.

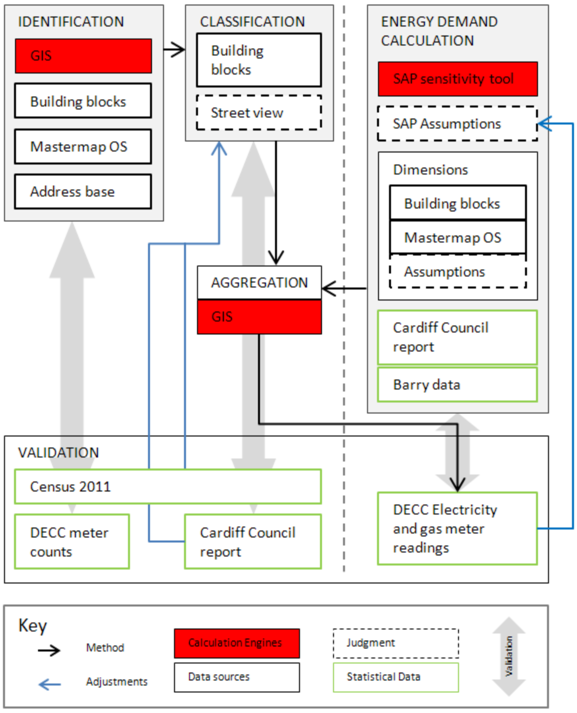

Figure 1: Overview of method

Identification and Classification of Dwellings

The accuracy of dwelling identification was fundamental in creating a reliable bottom-up energy demand model. Furthermore, the data used for classifying the stock needed to be as precise as was practically possible in order to maximise the meaningfulness of the aggregated results. The data sets used were GIS based making it possible to merge the relevant sources to form one data set with all necessary information for the energy demand model. A sample of the three sources used can be seen in figure 2 and were:

- *Building Block* (GeoinformationGroup 2013): Each block was categorised into one of five age bands and fifteen typologies with the height of the block representing the rough height of the related buildings, making it possible to approximate the number of storeys
- *Master Map Topography Layer* (OrdenanceSurvey 2013): Each polygon's area gave detailed ground floor area for each separate building
- *Address Base Premium* (OrdnanceSurvey 2013): Each point represented a current Royal Mail postal address with each classed by the use of the address making it possible to identify all residential addresses

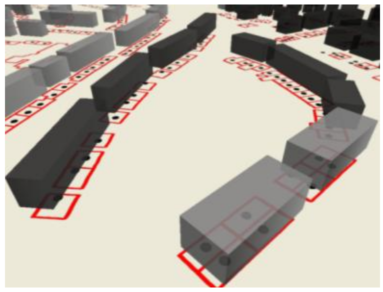

Figure 2: Data sources for the identification and classification of dwellings

<u>Incomplete data</u>

Although the data merged well in general, some problems arose due to inconsistencies in the coverage and creation date of sources. Building block data covers urban areas, therefore 6 of the 214 LSOAs had no classification or height data available. As a consequence they were not included in the case study. Other LSOA had incomplete building blocks data:

1. LSOAs on the periphery of the Local Authority had no data for some of the outer residential buildings, marked as crosses in figure 3
2. LSOAs with large new residential neighbourhoods developed since 2009, highlighted in dark gray in figure 3
3. LSOAs with a significant number of flats in commercial areas; black in figure 3

Three unique classifications relating to typology and age were given to these three groups of addresses so that they could be assigned with appropriate energy use approximations.

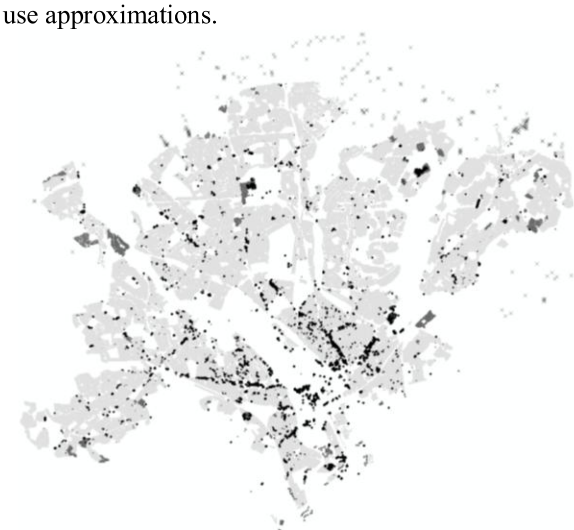

Figure 3: points representing residential addresses

A very small number of addresses had missing MasterMap Topography polygons, therefore a default floor area of 90m2 was assigned to each. Addresses with missing data accounted for just under 15% of those in the case study area.

<u>Validation</u>

Identification of Dwellings

The merged data set containing details of all residential addresses was the foundation for the model. It appeared to be a reliable starting point as the number of addresses identified in each LSOA agreed well with the number of households per LSOA in the 2011 Census (Statistics 2013). The comparison can be seen in figure 4.

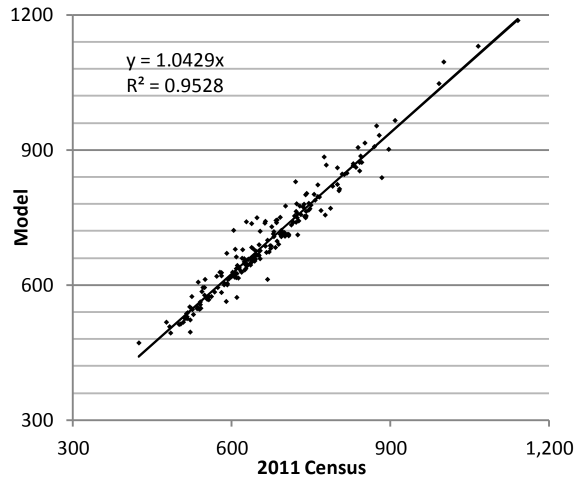

Figure 4: Number of dwellings in Cardiff LSOAs in 2011 census results and in model

Typology Classification

To simplify the process, 15 typologies were reduced to 4, retaining only the core typologies: detached, semi detached, terraces or flats. 2 of the original 15 typologies (semis in multiples of 4,6,8, and planned balanced mixed estates) and one of the newly created typologies (newly built mixed estates) were initially considered to be semi detached. Comparing the distribution of the 4 core typologies with census 2011 data on typologies for the Cardiff Local Authority suggested that this assumption was not just and could lead to inaccurate results. *Google's Street view* and differences in the distribution when compared to Census 2011 data was used to re-categorise these 3 typologies. This can be seen in figure 5 and are the classifications used in the final gas and electricity demand results.

Classification of Age

Very few data sources existed that detailed the age of dwellings in depth. However, two sets of data were used to verify the age classifications and to aid in classifying those with missing data. The Living in Wales survey was conducted in 2008 and gives an overview of the construction period of dwellings across Wales. Cardiff County Council's private sector stock condition survey conducted in 2005 gives an idea of the distribution specifically within Cardiff Local Authority although it does not represent the full stock (FordhamResearch 2005).

The percentage in each age group from these two surveys along with the mapped data can be seen in figure 6. Over 90% of the unclassified addresses in terms of age are those with missing data. 8% of those (dark gray in figure 3) were assumed to be newly built since 2009 and therefore were easily classified as post 1979. This left a remaining 7% which both surveys suggested to be pre 1919 dwellings. These mostly consisted of dwellings outside the urban area or flats in commercial areas.

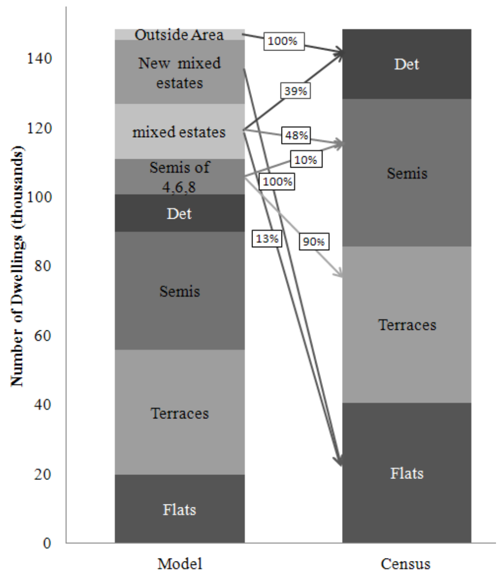

Figure5: Re-categorisation of Semis in multiples of 4,6,8 and mixed estates

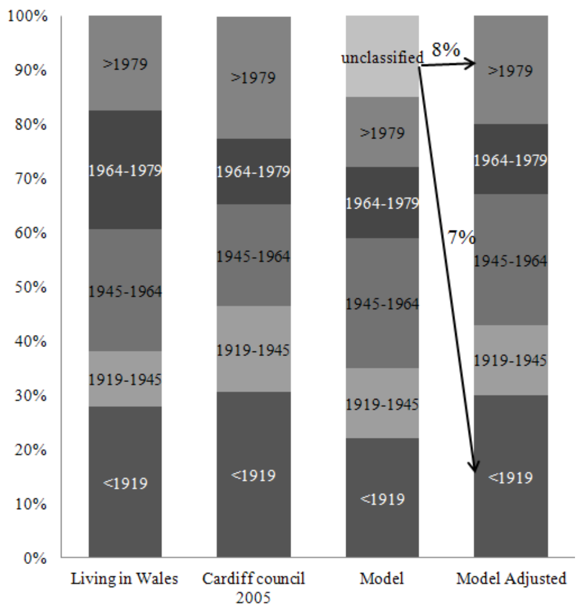

Figure 6: Age of dwellings comparison

Energy Demand of Dwellings

Monthly BREDEM based SAP tool

SAP is the UK energy compliance model that quantifies a dwelling's performance in terms of energy use per unit floor area based on the BRE's Domestic Energy Model (B R Anderson 1997). It takes into account the building's construction, location, heating systems and controls. The SAP sensitivity tool is based on a monthly version of BREDEM and estimates the energy consumption of space heating, water heating, lighting, electrical appliances and cooking. In BREDEM the total monthly energy use is calculated as outlined by EQUATION 1 (B R Anderson 1997).

$$Q(m) = Q_{prim}(m) + Q_{sec}(m) + Q_w(m) + E_{Lm}(m) + E_{Km}(m) \quad (1)$$

One of BREDEM's objectives is to compare different energy efficiency measures and *"to carry out a detailed study of a particular house or household, using specific occupancy information"* (B R Anderson 1997). The SAP sensitivity tool assumes a defined level of comfort and service provision to be delivered under a standardised occupancy condition which is based on a standardised occupant heating regime, temperature and heating pattern as well as the use of hot water, lights and appliances and the contribution made by metabolic gains (B R Anderson 1997).

Simple Model with Limited Parameters

According to (Firth 2010), the average house's CO_2 emissions based on the 2001 English housing survey is most sensitive to changes in occupancy, dwelling size, boiler efficiency, wall U-value and window U-value. It is also stated that the key factors affecting space heating are the dwelling's age and its built form i.e., the number of exposed walls, floors and roofs as well as the total floor area. It was decided to simplify the 15 typologies to 4, retaining only the core typologies: detached, semi detached, terraces or flats, thus removing any details on dimensions and retaining only information concerning the exposure of outer surfaces.

The tool used is a web calculator designed to provide approximate SAP ratings by concentrating on the most crucial and commonly altered parameters, mostly relating to fabric and systems. Limitations have been made in the variety of information that the user can process, with the intent of preserving simplicity of use (E. Crobu 2013). Both inputs and outputs are visible on a single screen with a maximum of 12 values to choose from for each of the 22 variables. Two outputs of the tool were used in this model which were: electricity used (kWh/year) and space and water heating usage (kWh/year).

The variables are split into 3 groups: Building overview, fabric and systems. These give the basic but essential options needed to distinguish physical properties that influence energy demand:

Building Overview	**Fabric**	**Systems**
Location	Thermal mass	Primary heating fuel and system age
Typology	Walls U-value	Secondary heating fuel type
Floor Area	Floor U-value	Infiltration rate
Orientation	Roof U-value	Ventilation
Surface ratio	Windows U-value	Solar thermal
Obstacles	Glazing ratio	PV panels
Lighting	Window shading and overhang	
	Thermal bridging	

Figure 4: Variables in SAP sensitivity tool by group

Variables by age, type and dimensions

It was decided to further group the variables in terms of their dependency on age, typology or independency from both, i.e. variables which are dependent on occupants, impossible to predict on a generalised level, or are constant for all dwellings in this case study. This is highlighted in figure 4, with those dependent on age in gray, on typology in black and those independent in white. Physical parameters identified as having the greatest affect on CO_2 emissions were given as much consideration as possible.

Age

Initially, age dependent values were determined by considering dwellings as they would have been built. The most influential parameters were then altered using statistical data on refurbishment levels to create progressive refurbishment steps for each age group with each one weighted according to its prevalence as can be seen in figure 5. Values used for walls, roofs and windows were based on statistical data from a report on private housing stock condition by Cardiff Council {FordhamResearch, 2005 #8}. No data relating to age of dwellings were available for heating system efficiency therefore values were based on data collected from EPCs for a nearby region.

Age 1 (Pre 1919)	15%	5%	10%	15%	35%	10%	5%	5%
Wall U-value	2.1	2.1	2.1	2.1	2.1	2.1	1.7	0.45
Roof U-value	2	0.6	0.6	0.6	0.6	0.35	0.35	0.35
Window U-value	4.8	4.8	3.1	3.1	3	2.2	2.2	2.2
Heating: Age	<'06	<'06	<'06	>'06	>'06	>'06	>'06	>'06

Age 2 (1919-1945)	10%	5%	15%	10%	40%	20%
Wall U-value	2.1	2.1	1.7	1.7	1.7	0.45
Roof U-value	2	2	0.6	0.6	0.6	0.35
Window U-value	4.8	3.1	3.1	3.1	3	2.2
Heating: Age	<'06	<'06	<'06	>'06	>'06	>'06

Age 3 (1945-1964)	5%	10%	10%	5%	40%	10%	20%
Wall U-value	2.1	1.7	1.7	1.7	1.7	0.45	0.45
Roof U-value	2	2	0.6	0.6	0.6	0.6	0.35
Window U-value	4.8	3.1	3.1	3	3	3	2.2
Heating: Age	<'06	<'06	<'06	<'06	>'06	>'06	>'06

Age 4 (1964-1979)	5%	10%	15%	45%	5%	20%
Wall U-value	1.7	1.7	1.7	1.7	0.45	0.45
Roof U-value	2	2	0.6	0.6	0.6	0.35
Window U-value	4.8	3.1	2.2	3	3	2.2
Heating: Age	<'06	<'06	<'06	>'06	>'06	>'06

Age 5 (post 1979)	10%	5%	15%	20%	30%	20%
Wall U-value	0.6	0.6	0.6	0.6	0.35	0.35
Roof U-value	2	2	0.6	0.6	0.6	0.35
Window U-value	4.8	3.1	3	3	3	2.2
Heating: Age	<'06	<'06	<'06	>'06	>'06	>'06

Figure 5: Weighted average levels of refurbishment for age groups

Type

The three variables identified: typology, surface ratio and obstacles could be simplified and derived for the 4 typologies. A 4th variable, total floor area that is closely related to typology and is known to have great impact on energy consumption has not been considered as being dependent on type but treated independently.

Dimensions

Detailed dimensions were straightforward to derive from GIS for each individual dwelling and were introduced into the model. Floor area was identified as one of the major factors affecting CO_2 emissions (Firth 2010). (V. Cheng 2011) also observes that the increase in total floor area with rising income (or socio-economic class) results in higher energy consumptions. It is also mentioned by (Firth 2010) that there is linearity between increase in floor area and CO_2 emissions.

Calculated dimensions for all dwellings were combined with the energy use results by varying the floor area in the SAP sensitivity tool for each version of each classification. A linear equation (one for electricity use and one for space and water heating) was derived to represent the energy use of the 20 classifications' weighted averages, dependent on the individual dwelling's dimension.

Aggregation and Validation

Aggregation

GIS was used to assign the relevant linear equations to each identified dwelling making use of the calculated floor areas. This meant that, although the model was confined to only 20 building classifications, in theory, there could have been as many different values for electricity and heating energy demand as there were dwellings. The electricity and heating use calculated for each dwelling were then aggregated per LSOA based on their spatial location.

Validation

Domestic gas and electricity consumption data were available at LSOA level from DECC (DECC 2010). They were formed by aggregating the actual readings of all meters within the areas. This set of data was used to validate the model, although there are a few issues to be noted:

- The data used is from 2010, therefore there could be very new developments included in the model which would not be accounted for in this data
- This data only considers gas and electricity usage. It is estimated that 6-7% of dwellings in the Cardiff area use other fuels as their main source of heating and therefore would also not be accounted for in this data
- Some LSOAs could have more or less domestic gas meter readings than there is in reality as all properties using below 73,200kWh/year of gas is automatically counted as a dwelling and could in reality be small commercial or industrial properties or vice versa

The 2011 census results for the number of households per LSOA were used to consider the differences in number of electricity meters, gas meters and dwellings identified in the model. The meter comparisons can be seen in figure 6 and was taken into account when analysing the final results.

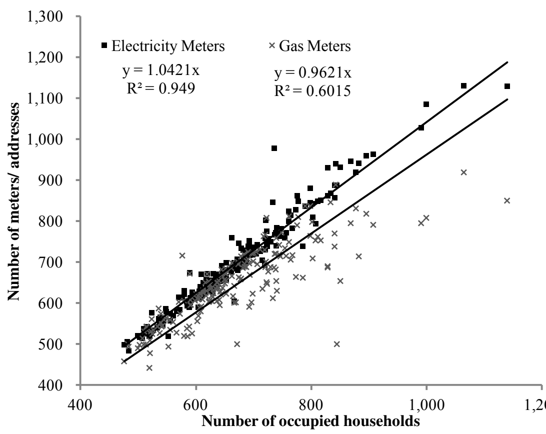

Figure 6: Number of households in 2011 Census against number of domestic gas and electricity meters in 2010 per LSOA

RESULTS

Domestic Electricity Consumption Results

The electricity consumption of dwellings aggregated per LSOA agreed with DECC's electricity meter readings on the same aggregated level. This can be seen in figure 7, which suggests that the method of combining the tool with the GIS data was successful.

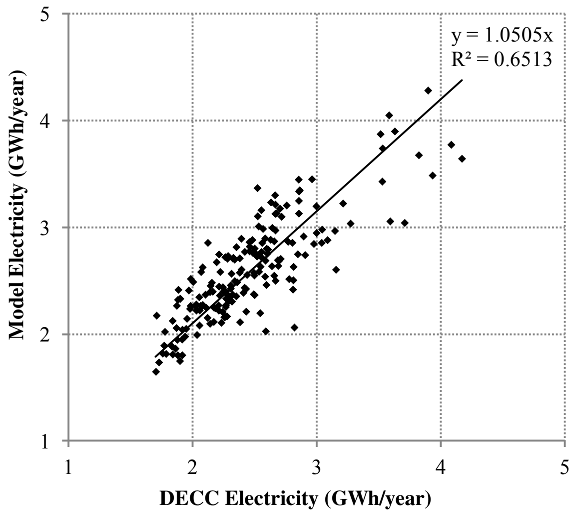

Figure 7: Model's Calculated Domestic Electricity Consumption compared to DECC electricity meter readings per LSOA

Initial Domestic Gas Consumption results

The initial results of dwellings' gas consumption compared with DECC's meter data, adjusted to account for off gas dwellings, was relatively precise but not as accurate as expected. The model seems to be overestimating energy demand for heating as can be seen in figure 8.

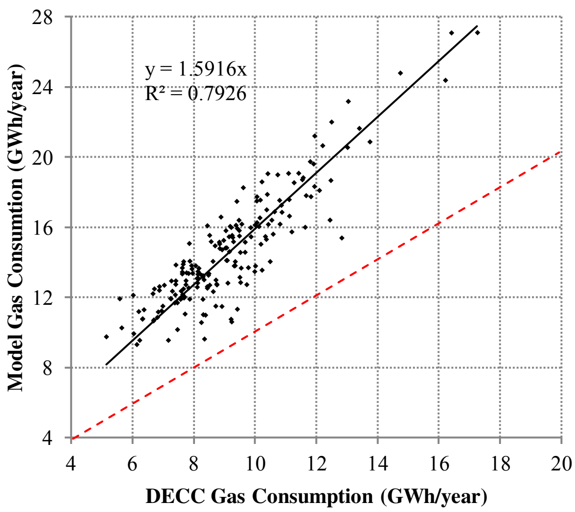

Figure 8: Initial Model's Calculated Domestic Gas Consumption compared to DECC's adjusted gas meter readings per LSOA

The model's performance in terms of electricity consumption implied that the method of inputting linear equations to represent weighted average levels of refurbishment for classified dwellings in GIS, in combination with data on dimensions, was reliable. In addition, it was shown that all sources were comparatively close when it came to the identification of dwellings (i.e. addresses and meters compared to the number of households per LSOA). This suggested that the overestimation of gas consumption was a consequence of the variables and assumptions used in the energy demand calculation and therefore were reviewed.

Four groups of variables and assumptions were considered questionable in terms of their accuracy and were identified as key factors affecting space heating:

- *Mean internal temperature* is highly dependent on occupants. SAP 2009 calculates the mean internal temperature for each month based on the heating requirement of a typical household while taking into account the physical properties of the dwelling. The mean is a combination of two values that are calculated; one for the temperature of the living area and another for the remainder of the heated space. The tool assumes that the living room is well heated at 21ºC with the rest of the heated spaces at 18ºC. (Wright 2008) suggests that in reality, these values could lie at around 20ºC and 19ºC respectively.
- *Heated floor area* could be slightly less than calculated in the model as the method assumes that all spaces within the perimeter of residential buildings are heated areas. This assumes that all spaces within the floor area are heated, when in reality, a portion could be unheated. It also does not account for the space taken up by the thickness of walls.
- *U-value of solid walls* could also be partly accountable for the overestimation. In situ measurements recorded in (C.Scott 2011) suggested that U values for traditional solid stone and brick walls are around 1.5W/m^{2}K which is much lower than the SAP recommendation of 2.1W/m^{2}K for pre 1919 dwellings.
- *Heating system efficiency* for gas central heating systems is defined by two values in the SAP sensitivity tool: Pre and post 2006. Estimation of their weightings in the model was based on data collected from EPCs for a nearby region. 20% of the sample of this region had G rated boilers with the rest rated above G. Translated to pre and post 2006, it was assumed that 30%

of dwellings had pre 2006 boilers (as is highlighted in figure 5) with 70% post 2006 boilers, i.e. A rated. The translation might underestimate the percentage that is A rated.

Refined Domestic Gas Consumption Results

Slight modifications were made to the 3 later variables above which brought the gas consumption predicted by the model closer to the aggregated meter readings. The model was then run under 5 different mean internal temperatures, from 17ºC to 21ºC as can be seen in figure 9. Considering the uncertainties associated with the measured meter readings, the refined results agree reasonably well. Figure 9 suggests that for dwellings in the Cardiff Local Authority, the average mean internal temperature is between 18ºC and 19ºC.

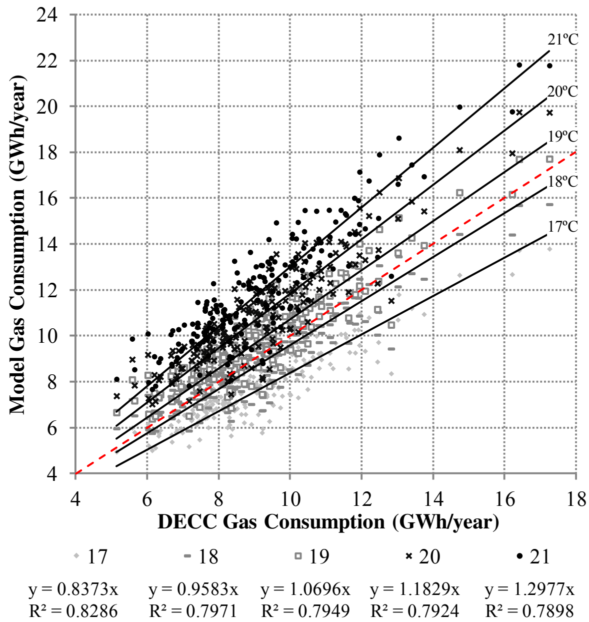

Figure 9: Refined model's calculated domestic gas consumption with 5 internal temperatures compared to DECC gas meter readings per LSOA

DISCUSSION AND CONCLUSION

It has been proved that the method of combining and refining the SAP sensitivity tool using GIS and data validation has the capability to model the energy consumption of a Local Authority in the UK. During its development, it was evident that accurate identification of dwellings was fundamental and that a similar level of care in validating the typologies and age would be needed if applied to other areas.

Initial refinement of the model proved successful and work will continue to improve the reliability further. The use of standard occupancy conditions has been identified by many as an inadequate estimation of real occupant behaviour due to a number of factors. Old dwellings are often heated to a lesser degree due to the compromise between running costs and thermal comfort while heating energy use is under predicted for contemporary dwellings due to generally higher indoor temperatures (Cambridge Architectural Research 2009). Moreover, (V. Cheng 2011) states that households in deprived and affluent areas are likely to have different lifestyles and therefore differ in their energy consumption. (T. Oreszczyn 2005)'s study of actual measured indoor temperatures of 1604 low income households in England found that the median standardized daytime living room and bedroom temperature was 19.1 °C and 17.1 °C respectively with differentiations depending on property and household characteristics. Although initial refinement of occupancy conditions proved successful, disaggregating occupancy related inputs further could provide more meaningful results. I.e. readily available Output Area level data on households in terms of age, income or fuel poverty and physical properties of dwellings could be used to further adjust indoor temperature set points in the model. Research on occupancy patterns could also be used in a similar manner and more detailed, statistically based data on heating systems and fuel type could be introduced. The inclusion of other fuel types could prove vital if the model were to be applied to more rural areas with a higher proportion of dwellings off gas.

A similar method of validation and refinement will be carried out when applying the model as a prediction tool for energy efficiency and renewable energy technologies. This will investigate the capabilities of SAP based models in forecasting the impact of such energy saving efforts. (V. Cheng 2011) refers to past research that has found a consistent overestimation of the predicted savings in energy use and CO_2 emissions from retrofitting measures, known as the 'rebound' or 'take-back' effect. (S. H. Hong 2006) compared property and utility consumption data as well as room temperatures over a 2–4 week period over two winters from a total of 1372 properties. Between the two winters, loft insulation, wall insulation and new heating systems were installed in a sample. The differences in fuel consumption were compared with predicted improvements (based on a simple BREDEM model), but actual reduction was far less than anticipated. The evidence and reasons for discrepancies identified in such studies will be integrated into the next stage of the model.

It is hoped that with these advancements, the model could be effectively used and be a valuable prediction tool for energy efficiency and renewable energy technologies for Local Authorities and any area in the UK from neighbourhood to national level.

NOMENCLATURE

$Q(m)$	= Total monthly energy use (GJ)
$Q_{prim}(m)$	= Fuel used in primary heating system for each month (GJ)
$Q_{sec}(m)$	= Fuel used in secondary heating system for each month (GJ)
$Q_w(m)$	= Fuel requirement for water heating for each month (GJ)
$E_{Lm}(m)$	= Electricity consumption for lights and appliances for month m (GJ)
$E_{Km}(m)$	= Cooking fuel consumption for month m (GJ)

ACKNOWLEDGEMENT

This research is part of the Low Carbon Built Environment project, supported by the European Regional Development Fund through the Welsh Government.

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Paper 8 - Modelling urban scale retrofit, pathways to 2050 low carbon residential building stock

Lannon, S. C., Georgakaki, A. and Macdonald, S. 2013. Modelling urban scale retrofit, pathways to 2050 low carbon residential building stock. Presented at: 13th International Conference of the International Building Performance Simulation Association, Chambéry, France, 25 - 28 August 2013.Proceedings of BS2013: 13th Conference of the International Building Performance Simulation Association. International Building Performance Simulation Association (IBPSA), pp. 3441-3448.

My Contribution in this paper

This paper was the culmination of a JISC funded research project STEEV, in which I completed all the energy simulation required to develop a tool that considered the energy performance of dwellings both spatially through GIS and temporally through scenario work.

My co-authors contributed through the provision of background scenario work and the development of the web interface to display the scenario modelling results. As lead author I developed all the modelling and generation of results.

MODELLING URBAN SCALE RETROFIT, PATHWAYS TO 2050 LOW CARBON RESIDENTIAL BUILDING STOCK.

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ABSTRACT

A bottom up engineering modelling approach has been used to investigate the pathways to 2050 low carbon residential building stock. The impact of housing retrofit, renewable technologies, occupant behaviour, and grid decarbonisation is measured at a local authority scale. The results of this exercise were visualised using a client web application, or 'demonstrator,' which was developed to allow stakeholders to engage with the modelling process.

INTRODUCTION

The UK government has set an ambitious target of 80% reduction of carbon emissions by the year 2050. As part of this target, it is predicted that the emissions related to buildings in 2050 will need to be close to zero. While the design of new zero carbon buildings has been researched, the potential for zero emission retrofit is less well known. As the vast majority of buildings that will exist in 2050 have already been built, and the interactions of the carbon emission reduction methods, such as fabric improvements, occupant behaviour and renewable technologies in the urban retrofit design process need to be researched further.

The Welsh Government have committed to achieving annual emissions reductions of 3% carbon equivalents in areas within their competence (WAG, 2010a). The target includes all direct GHG emissions in Wales except those covered by the EU ETS. In addition, power generation emissions (covered by EU ETS) are also included in the 3% target, by assigning them to the end-user in each of the non-EU ETS sectors. This is in recognition of the importance of reducing electricity consumption as part of achieving sustainability goals. Taking the above into account, the residential sector becomes a key target area for reductions as it represent 30% of the emissions within Welsh Government competence (WAG, 2008) and the aspiration has been expressed to make all new buildings "zero carbon" in future.

Other goals include reducing the use of carbon-based energy by 80-90%, and at least matching electricity consumption in Wales with power generated from renewable sources by 2025 (WAG, 2009) which would translate to more than 30TWh of renewable electricity and 3TWh of renewable heat per year. More ambitious views have also been expressed, which involve generating twice as much renewable electricity in 2025 as presently consumed in Wales, and covering all local energy needs by low carbon electricity by 2050 (WAG, 2010b).

In this context, local authorities in Wales share the responsibility of improving and maintaining building stock condition to certain levels of sustainability (NAW, 2001), and promoting the deployment of renewable energy schemes in their area (WAG, 2010c). The Welsh residential sector has a larger share of hard to treat properties compared to the rest of the UK. This could mean higher potential for energy efficiency improvements but also higher associated marginal costs (Baker and Preston, 2006). There is currently no representative residential stock model for Wales, and studies quoted in literature model the region based on data from other parts of the UK (Hinnels et al, 2007).

In view of the policy targets and stakeholder responsibilities at the local authority level, it is necessary to obtain a more accurate portrayal of the sector in order to address stock-specific constraints and opportunities in Wales. Recent research has used a top-down model to derive insights on the impact of retrofit measures at local authority level (Gandhi et al. 2012). Focusing within the local authority at a lower level, this bottom-up approach goes one step further to demonstrate the possibility of providing policy makers and stakeholders at the local level with valuable information on the potential for retrofit based or area specific data.

Background

Modelling the energy use of buildings at an urban level has been undertaken for many years, and different models have been created of which the majority fall into one of two approaches, top down or bottom up (Swan and Ugursal, 2009).

Top down is commonly used as a statistical model of the built environment based on demographic data from sources such as the census and other national datasets. This information is applied at lower levels of geography to give area-based resolution of the modelling. Examples of top down include the UK Department of Energy & Climate Change (DECC) 2050 calculator (DECC 2011), The Economics of

Low Carbon Cities (Gouldson et al, 2012), DeCarb (Natarajan, 2007).

Bottom up models, sometimes known as engineering models use data on individual buildings that are aggregated up to the larger scale. The individual buildings can be grouped together or classified into archetypes to aid the data collection and modelling process (Jones, et al, 2007)

A model that attempts to bridge the gap between academic endeavour and the public is the DECC 2050 calculator, an emission model for all sectors of the UK economy, which considers a number of options for each sector based upon economic and energy models .

SCENARIOS AND PATHWAYS

Many pathways and scenarios have been created to show how emission reduction targets can be achieved, for example, Carbon Trust "Building the future today" (Carbon Trust, 2009), but they are generally based on a top down approach. Therefore, they tend to give broad guidance on the impact of the work on the ground. In this work, a framework has been developed to take these top down approaches and merge them with a bottom up model of a large urban area based on the Energy and Environmental Prediction (EEP) model (Jones, et al, 2000).

The grid decarbonisation pathways chosen for the modelling process have taken data and waypoints from the UK Energy Research Centre (UKERC) 2050 Carbon Pathway (DECC 2011). Concepts regarding affordability of energy efficiency measures have been taken from the Carbon trust "Building the future, today" research (Carbon Trust, 2009).

The outcome of the scenario analysis was three example possible future scenarios:

Scenario 1 – Faint Hearted

Generally business as usual, some minor attempts to decarbonise the grid and continued slow energy efficiency update.

Scenario 2 – Low Carbon Reference

The government invests in partial decarbonisation of the grid through reduced dependence on fossil fuels. Large investment in energy efficiency and small scale renewable, some change in occupant behaviour.

Scenario 3 – Super Ambitious

The government invests in full decarbonisation of the grid through renewable, nuclear, and huge investment in energy efficiency and small scale renewable. There is also large scale change in occupant behaviour.

Each of these scenarios can be broken down into four components that have an impact on the emissions of buildings; the electric national grid, small-scale renewable technologies, energy efficiency and occupant behaviours. Choices for these components are introduced in the model through sliders, covering the range of change corresponding to the scenarios described above.

The Grid

The supply of energy in the UK is usually through the national grid, which uses a mix of fuel sources to generate electricity. This mix, which includes fossil fuels, has an overall emission rate for each unit of energy delivered to houses. The government plans to reduce this emission rate by decarbonising the grid. This slider represents the government policy range from business as usual Faint-heart with 0.422 kg CO_2 per kWh to super ambitious decarbonisation with 0.08 kg CO_2 per kWh.

Renewables

Small scale or building renewable energy systems can help to reduce the carbon emissions of buildings. This slider selects the number of photovoltaic panels installed on buildings, from around 10% to over 80% of houses having some or their entire roof covered in panels.

Energy Efficiency

There are simple measures currently available to reduce energy use in the home. These include loft insulation, new boilers, double glazing and low energy lighting. However, if houses are to reach the targets set by the government, options that are more expensive need to be considered, for example external wall insulation. This slider varies from a business as usual scenario to 100% uptake of simple measures and to a nearly 100% uptake of expensive options.

Occupant Behaviour

The way people use their houses has an impact on energy use. This slider changes the indoor temperature of the house set by the occupant; it varies from 21 degrees C to 17 degrees C representing a business as usual scenario to large scale change in user behaviour, i.e. lower expectation for indoor temperatures and more clothes worn.

CASE STUDY AREA

The area chosen for the case study is Neath Port Talbot County Borough Council (NPTCBC). Based on DECC estimates (DECC, 2007) NPTCBC contains 4.7% of the households in Wales, which compares well with UK National Atmospheric Emissions Inventory (NAEI) data (NAEI, 2008) attributing 4.4% of domestic emissions to the area.

Domestic EEP Database

The data used in the case study area is based on the surveyed properties entered into the EEP database.

The list of domestic properties for the county borough was generated from the Postal Address File and the Ordnance Survey Addresspoint file supplied by NPTCBC. This contains 58,041 domestic properties of which 55,148 have been entered into the

EEP database. The properties missing were not surveyed due to incorrect addresses, nondomestic properties, hidden from view derelict and very isolated rural properties.

The ages of the domestic properties have been grouped into four major periods of building construction. The breakdown of property ages in Wales and NPTCBC figures 1a and b, shows NPTCBC has more pre 1919 properties (33% to 35%) and less post 1964 properties (25% to 23%), when compared to the Welsh figures.

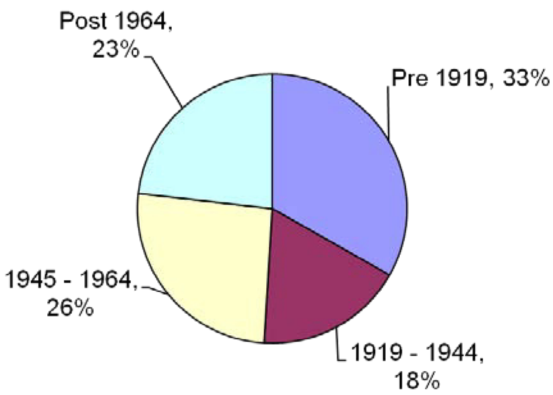

Figure 1a Property age breakdown for Wales

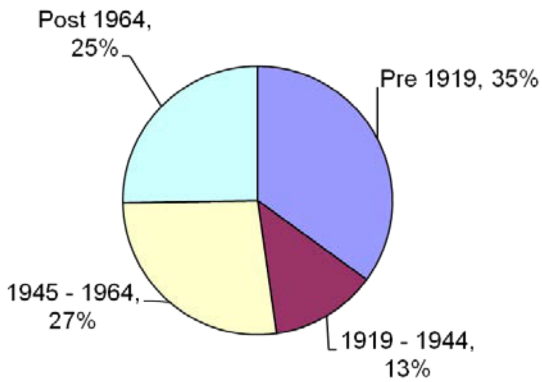

Figure 1b Property age breakdown for Neath Port Talbot

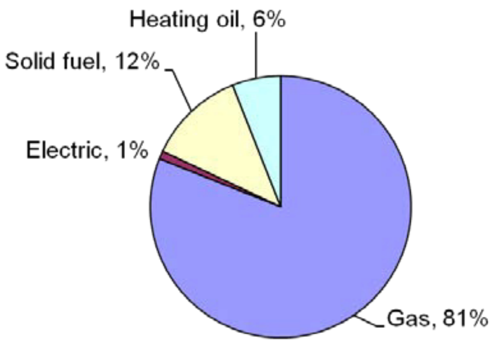

Figure 1c Heating fuel type breakdown for Neath Port

Domestic properties in NPTCBC are predominately two storeys (83%), with single storey (16%) and three storeys (1%) making up the remainder. The fuel used for space and water heating was established from a household questionnaire sent to 2,000 households, which asked occupants in NPTCBC questions relating to, heating type and fuel, age of heating system and if any energy efficiency measures are installed. The breakdown for fuel type is shown in figure 1c.

METHODOLOGY

The web application or demonstrator aims to provide a clearer understanding of how urban transitions can be undertaken to achieve UK and international targets to reduce carbon emissions. It enables researchers and stakeholders including policy makers to look at how the spatial and temporal distribution of energy efficiency measures may impact upon likely regional outcomes for a given future state. This takes the form of a spatio-temporal exploration and visualisation tool for building-level energy efficiency modelling outputs such as the energy rating of the building, the likely energy demand of the building and the related CO_2 emissions. A finite series of modelled scenario permutations have been 'pre-built' thus providing a controlled number of parameters to be interactively altered in order to explore the spatio-temporal consequences of various policy measures.

Demonstrator development

The demonstrator, developed at the EDINA National Data Centre, University of Edinburgh as part of the JISC-funded Spatio-Temporal Energy Efficiency Visualisations (STEEV) project, is a JavaScript client application which uses Open Layers as the mechanism for displaying the map data over the web. It also deploys a Web Map Service with temporal querying capabilities (WMS-T) to deliver Ordnance Survey open mapping products via the Digimap OpenStream API. The modelled energy efficiency variables are held in PostGIS (an open source spatial database extension to PostgreSQL)

Initially the design was built upon the DECC 2050 idea of standard user interface objects such as sliders and buttons to allow the user to interact with the modelling. This was combined with a web-based interface to allow the users to spatially explore the scenario process. Such spatial interrogation of geo-referenced information is becoming more common through the use of accessible and user-friendly open mapping services and utilities from e.g. Google and Ordnance Survey data.

Usability

During the development phase, a usability review of the demonstrator was conducted. Several areas of the web interface were streamlined including making relationships explicit between the policy-based scenarios and the customisable scenarios compiled from the variable set, as well as between the policy scenario controls and the timeline (figure 2).

Simulation process

The simulation of the urban environment is a complex process; the EEP methodology simplifies this by using simple standard energy prediction tools, and ways of grouping houses together. The grouping of houses usually follows the type of house e.g. terraced, semi detached or detached, which is reasonable for simple problems, but when trying to predict the energy use of a detached house it could be two ends of a very large scale, from a labourers cottage to a mansion. The best way to group houses in this project is by their size and when they were built. To do this a number of common house types are surveyed, and the results of these surveys are clustered together to give groups of houses with similar energy predictions.

The EEP model uses the UK government specifies the Standard Assessment Procedure (SAP) (BRE, 1998) as the method for measuring the carbon emissions for electric lighting, space and water heating related to residential building stock. The model within EEP has been adapted to allow the modelling of fabric retrofit, building integrated renewable technologies and occupant behaviour. The EEP model allows for "what if" functions to target different retrofit options, and this capability has been developed further using the aforementioned combination of a web user interface and a web mapping tool. This demonstrator allows the user to explore the relationship between the factors in both a spatial and temporal manner; the results can be exported to Google Earth or other open geo-utilities for further analysis whilst also allowing an individual building or a small area to be tracked through time.

As a large numbers of dwellings are considered when studying a city or region, it is important that the information about each dwelling is easily collected and modelled. A procedure was developed for use within the model that groups together dwellings with similar energy performance characteristics creating 'house types'. This needs fewer calculations when the whole or large sectors of the local authority are investigated. For example, if all houses within an area can be reduced to 100 types, then subsequent calculations only have to deal with 100 house types and not every house (for example, 55,000) in the area. This allows real time calculations to be carried out, such as estimating the consequences of applying specific energy saving measures.

A cluster analysis technique was used to identify dwellings with similar energy consumption and carbon dioxide emissions. The cluster analysis procedure 'forces' dwellings into a specified number of groups or 'clusters' based on selected built form characteristics and the age of the dwelling. The five characteristics used to describe an individual dwelling in order to create clusters are:

- heated ground floor area (m2);
- facade (m2);
- window to wall ratio;
- exposed end area (m2);
- property age.

These features are considered to have the greatest influence on domestic energy performance. Other features, such as heating system, insulation level, percentage of energy efficient lighting, type of glazing were estimated from the age of the property and were used within the SAP calculations.

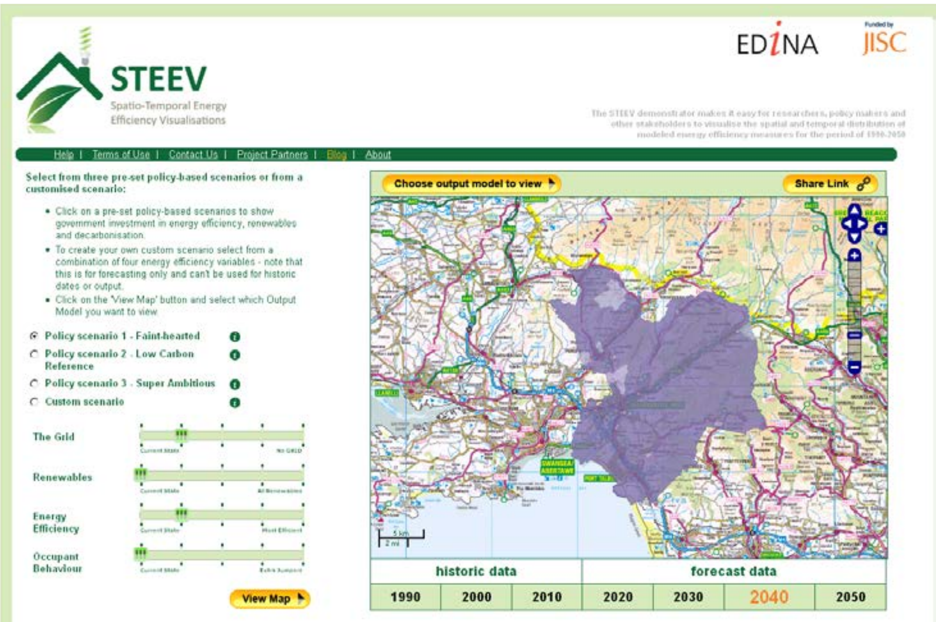

Figure 2 Web based demonstrator

Clustering results

In this case study 100 clusters were by date of construction, 34 for pre 1919, 13 for 1919 to 1944, 27 for 1945 to 1964 and 23 for post 1964. These numbers reflect the age breakdown for the local authority area. When the clusters are applied to the case study area, it was found that fourteen clusters represent over 67% of the dwellings, and cluster 55 represents 13.6% of the dwellings (Table 1).

Table 1
Clustering breakdown for case study area

Cluster Number	Built Age	Percentage
55	1945 - 1964	13.6%
4	Pre 1919	8.6%
2	Pre 1919	8.4%
36	1919 - 1944	7.4%
88	Post 1964	4.9%
82	Post 1964	3.9%
22	Pre 1919	3.3%
58	1945 - 1964	3.2%
94	Post 1964	2.8%
8	Pre 1919	2.6%
7	Pre 1919	2.3%
11	Pre 1919	2.3%
5	Pre 1919	2.2%
57	1945 - 1964	2.1%
75 clusters with less than 2%		32.3%

An example of one of the clusters shown in Table 1, in this case cluster 88 (figure 3), this type of building is a 100m^2 two storey brick cavity wall construction semi detached house built during the period 1945–1964.

Figure 3 Example of cluster 88 dwelling

Modelling approach

The SAP modelling method is based on the BREDEM model (Anderson, 2001) and uses a monthly steady state energy balance model of a building to calculate the space and water heating demands for typical occupancy pattern and climate conditions. The efficiency and the Carbon dioxide emission rate of heating and lighting systems are then applied to the heating demands to give an emission rate for each dwelling.

A SAP result was calculated for each of the 100 'house types' found in the NPTCBC data. Further SAP analysis was undertaken to allow for the effect of the different combinations of the three interventions considered: small-scale renewable technologies, energy efficiency, and occupant behaviour, results for this further analysis on a sample cluster shows that the reductions in carbon emissions can vary greatly (figure 4).

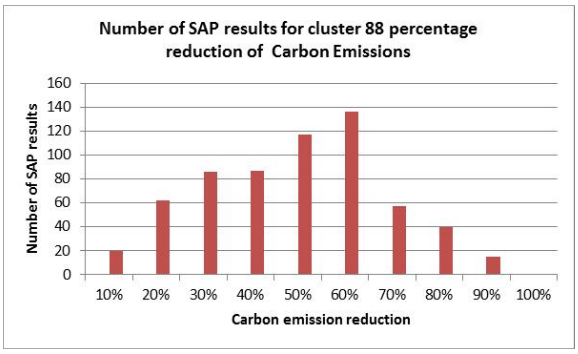

Figure 4 SAP analysis for cluster 88 for all the scenarios

The groups of houses are then modelled using the SAP technique to give a baseline or start point. From this baseline these groups of houses are modified to improve the energy efficiency, bolt on solar panels and take into account potential changes in the occupant's behaviour. A more detail description of the changes considered are shown in table 2. For example, it has been assumed that the occupants might accept low inside temperatures by wearing more clothes.

The prediction of energy use for each of these modifications is undertaken then applied to each of the houses in the sample area, in this case most of the houses in Neath Port Talbot, South Wales (around 55,000).

Occupant behaviour also has an impact on whether a particular type of modification will take place. This is represented in this project by trigger points for ten year steps from 2020 to 2050. The trigger points represent occupant behaviour year by year, and are associated with the likelihood of an occupant undertaking energy efficiency measures. The impact of energy efficiency measures is modelled by a series of trigger points that end with all the houses in the

Table 2
Factors for the pathways

PARAMETER	LOW SETTING	MIDDLE SETTING	HIGH SETTING
The grid	Faint-heart 0.422 kg CO_2 per kWh	Low carbon reference 0.225 kg CO_2 per kWh	Super Ambition decarbonisation 0.08 kg CO_2 per kWh
Renewables	By 2050, 32 % uptake of small solar panels, 16 % uptake of large solar panels	By 2050, 48 % uptake of small solar panels, 24 % uptake of large solar panels	By 2050, 80 % uptake of small solar panels, 40 % uptake of large solar panels
Energy efficiency	By 2050, 40 % uptake of cost effective energy efficiency, 32 % uptake of non cost effective energy efficiency	By 2050, 60 % uptake of cost effective energy efficiency, 48% uptake of non cost effective energy efficiency	By 2050, 100 % uptake of cost effective energy efficiency, 80 % uptake of non cost effective energy efficiency
Occupant behaviour	Room temperature 20 deg C	Room temperature 19 deg C	Room temperature 17 deg C

area having at least simple energy efficiency measures, and 50% having a more expensive energy efficiency measure such as external insulation cladding.

DISCUSSION

The task was to model 55,000 houses over 50 years in ten year steps, for 625 different scenarios, as sum total of around 172 million calculations and 9 GB of data. The modelling process was more complex than initially thought, and with hindsight, perhaps the sample should have been smaller.

Overall scenario results

Each of the factors investigated was given 5 levels of performance, from business as usual, faint-heart, low carbon reference, ambition decarbonisation, to super ambition decarbonisation. The overall results of the 625 scenarios show that only 10 have an outcome that will achieve the initial target of above 80% reduction in carbon emissions over the baseline of 1990 (figure 5).

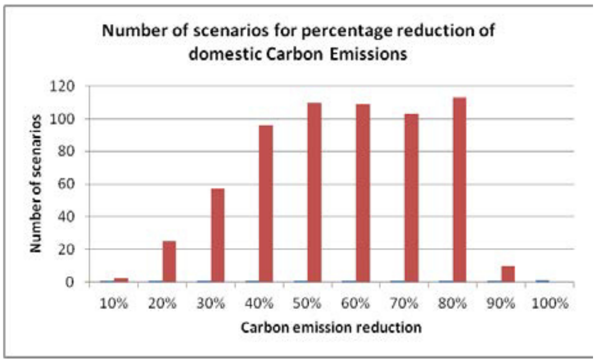

Figure 5 Overall carbon emissions reductions for all scenarios

The ten successful scenarios all had the grid decarbonisation and occupant behaviour set to the highest level of change. The energy efficiency uptake was the next important factor with the settings from low carbon reference to super ambitious achieving the target. The least significant factor is the small scale renewable technology.

The results of the simulations have been compiled and as part of the STEEV interface three sample scenarios have been selected for users to explore. These three sample scenarios show a reduction of

- 25 % for the "Faint Hearted",
- 52% for"Low Carbon Reference"
- 78% for Super Ambitious

Bottom up results

Scenarios are considered successful when the overall target is achieved, yet at a bottom up level, where information is available at a house level, the different scenario outcomes can reveal the spread of reductions achieved.

Two of the successful scenarios (scenario 615 and scenario 525), have been analysed at the dwelling level. In (scenario 615) the grid decarbonisation, the small-scale renewable technology and occupant behaviour are set to the highest level of change. The energy efficiency uptake was set to the middle level of change. In (scenario 525) the grid decarbonisation, energy efficiency uptake and occupant behaviour are set to the highest level of change. The small-scale renewable technology uptake was set to the lowest level of change.

The distribution of the carbon reductions for the two scenarios (figure 6) shows that some dwellings are over achieving whilst others are under achieving. These differences can be investigated at a finer detail geographical level by downloading the results from the STEEV interface and viewing the data within a Geographic Information System (figure 7).

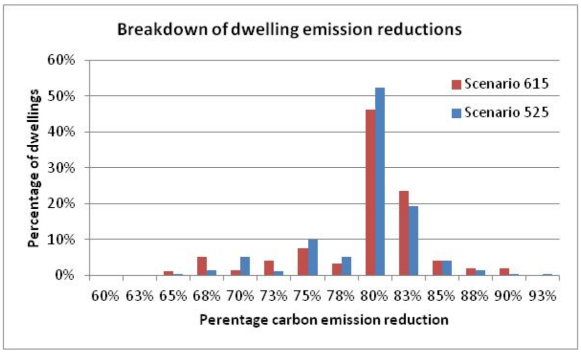

Figure 6 Carbon emissions for dwellings based on sample scenarios (scenario 525 and 615)

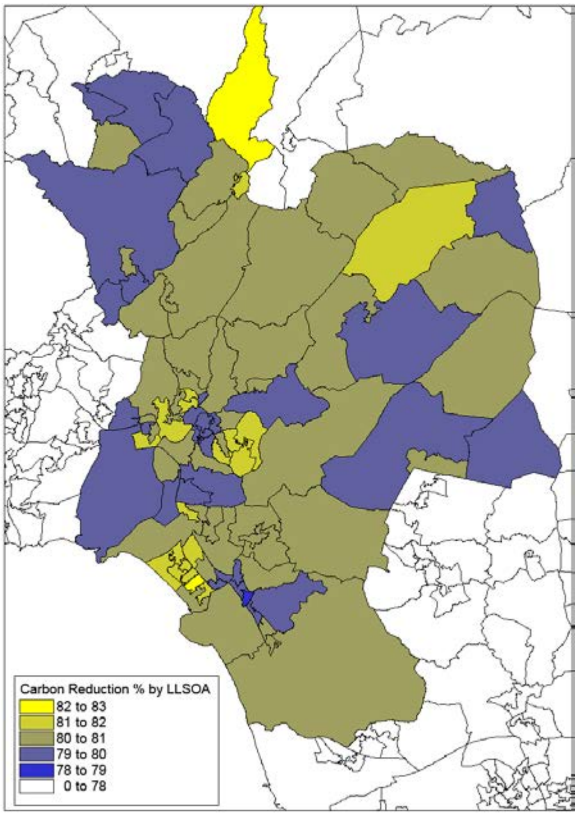

Figure 7 Lower level super output area results

CONCLUSIONS

In total 625 pathways were modelled for the Neath Port Talbot local authority, using a bottom up approach in combination with pre-existing energy efficiency scenarios. Out of the 625 pathways only ten achieved the 80% overall reduction target, the failed pathways were mostly hampered by limited grid decarbonisation and the lack of change in occupant behaviour.

The overall outcomes of these scenarios at a local authority level can be investigated at a lower level allowing the user to explore and display a variety of changes in the scenario make up. Whilst the overall target may be achieved in a target area, in one of the successful scenarios 22% of the dwellings reduce carbon emissions by less than 80%. The cases where energy consumption and emissions are not sufficiently reduced by the measures described, could be targeted for further more significant retrofit options.

This type of modelling can provide a useful measure of the impact of retrofit methods, but it also suggests that new methods need to be considered for retrofitting urban environments. These benefits must be set against the considerable effort required to create the base data required by a bottom up modelling approach.

ACKNOWLEDGEMENTS

The authors would like to thank JISC for funding the web application development (http://steevsrv.edina.ac.uk/) as part of the Information Environment Programme, Geospatial strand - http://www.jisc.ac.uk/whatwedo/programmes/inf11/jiscGEO/e3viz.aspx .

The scenario work was funded through the Low Carbon Research Institute's Convergence Cross Cutting Themes project "Scenario Modelling for Low Carbon Wales" which is supported by the European Regional Development Fund through the Welsh Assembly Government.

Finally thanks to the project team from the Re-Engineering the City 2020-2050: Urban Foresight and Transition Management project (EP/I002162/1) funded by the Engineering and Physical Sciences Research Council (EPSRC) for their feedback on the work. http://www.retrofit2050.org.uk/

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Paper 9 - Intensive building energy simulation at early design stage

Jones, P., Lannon, S., Li, X., Bassett, T. and Waldron, D. 2013. Intensive building energy simulation at early design stage. Presented at: Building Simulation 2013 (BS2013): 13th International Conference of the International Building Performance Simulation Association, Chambéry, France, 25-28 August 2013. Proceedings of BS2013: 13th Conference of the International Building Performance Simulation Association. International Building Performance Simulation Association (IBPSA), pp. 862-869

My Contribution in this paper

This work was also part of the Low Carbon Built Environment project, and as work package leader I developed the research aims to develop the earlier work undertaken in Paper 4 and 5 into a retrofit options tool not only for the UK but for other locations throughout the work. I developed all of scripts and coding required to create the tool based on the contemporary literature.

In particular my contribution to this paper is the development of the variant editing scripts and running the modelling for the 4,068 simulations. I developed the interface for the CAST model and the database behind it. The other work in this paper describes the VirVil plugin which I helped to write and develop.

The work in the paper that I completed shows the benefits of modelling in a complex manner when considering the urban scale. The outcomes have been applicable to real case studies that require detailed modelling at an early stage. This last paper is the end point of the research, but also points to future work to consider the impact of urban climate.

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To whom it may concern,

Regarding the paper:
Jones, P., Lannon, S., Li, X., Bassett, T. and Waldron, D. 2013. Intensive building energy simulation at early design stage. Presented at: Building Simulation 2013 (BS2013): 13th International Conference of the International Building Performance Simulation Association, Chambéry, France, 25-28 August 2013. Proceedings of BS2013: 13th Conference of the International Building Performance Simulation Association. International Building Performance Simulation Association (IBPSA), pp. 862-869

I worked with Simon on the EPSRC funded projects related to the Development of the EEP model this paper is a result of the research undertaken. This paper describes the work undertaken in the Papers 4 and 5. It particular Simon's contribution to this paper is the development of the variant editing scripts and running the modelling for the 4,068 simulations. Simon developed the interface for the CAST model and the database behind it. The other work in this paper describes the VirVil plugin which he helped to write and develop.

If you have any questions regarding this matter please do not hesitate to contact me.

Yours sincerely,

Prof Phil Jones

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.

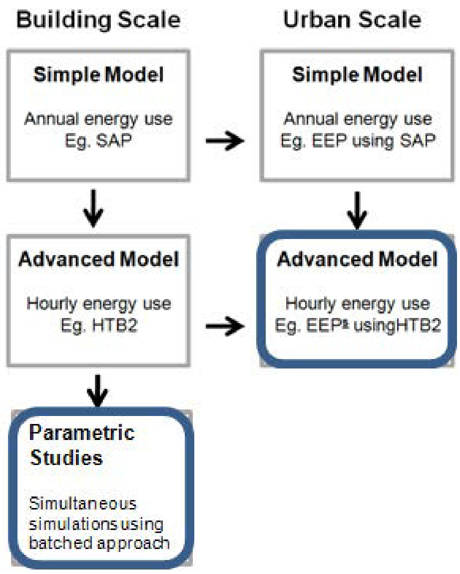


Figure one Development of building energy simulation highlighting the two developments in this paper

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.

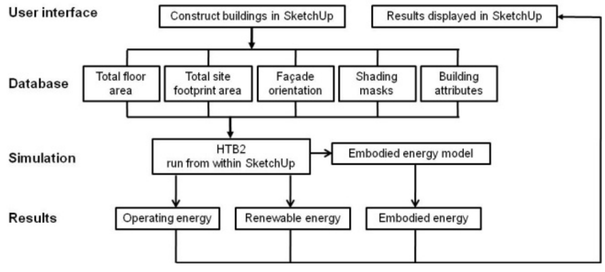


Figure 2 Structure urban modelling framework

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.

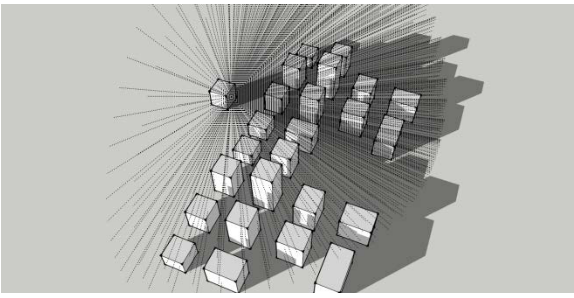


Figure 3 Surrounding awareness.

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)).

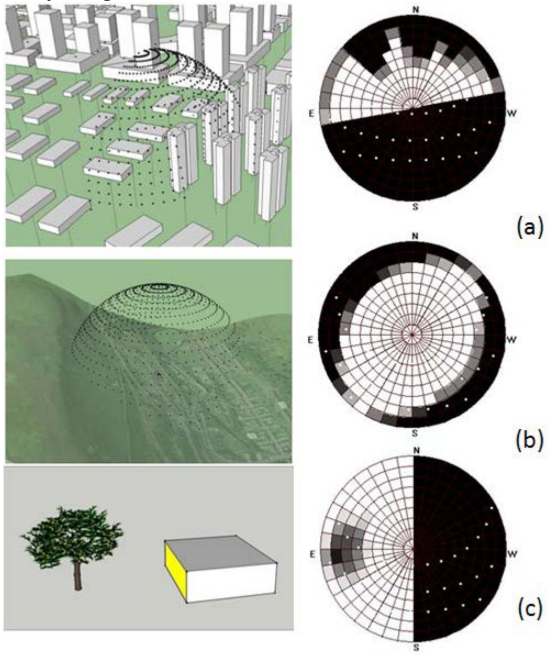


Figure 4 The shading effect on a facade with its resulting shading mask for (a) neighbouring buildings, (b) topography, (c) landscape features.

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.

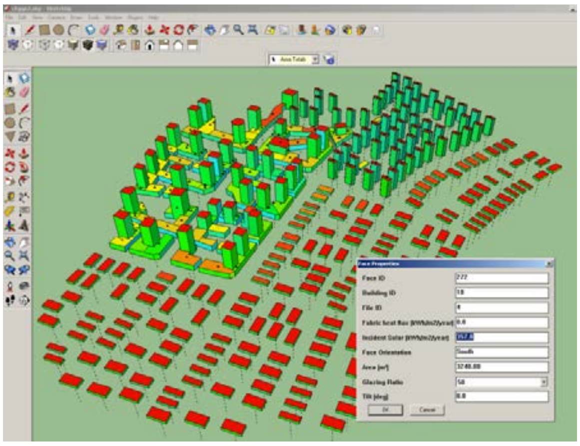


Figure 5 Solar radiation results displayed in SketchUp

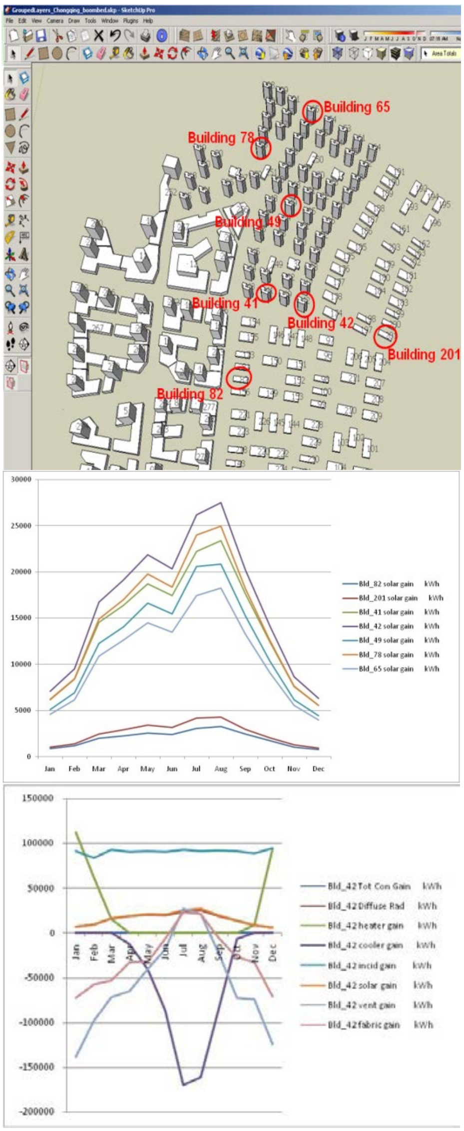


Figure 6 Energy analysis output for specific buildings and elements of energy performance for the whole development.

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.

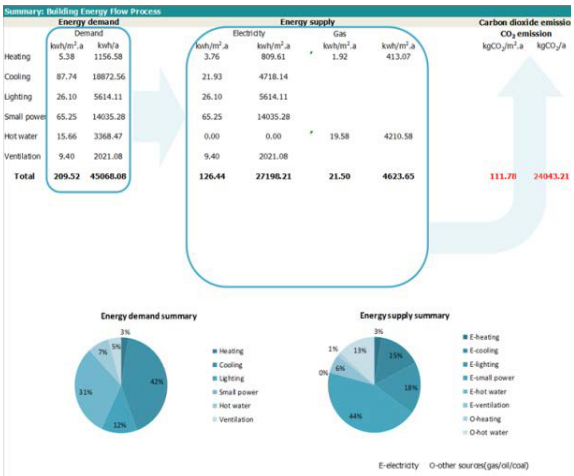


Figure 7 energy demand, supply and carbon dioxide emissions for the whole site

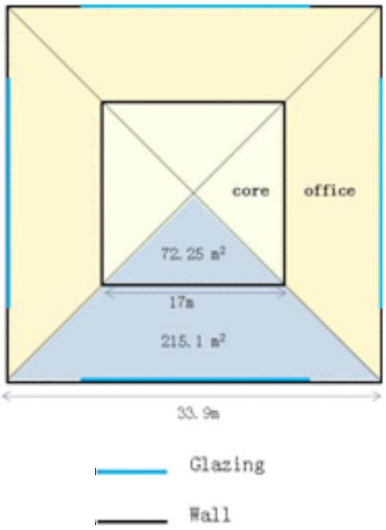
MULTI-PARAMETER SINGLE BUILDING MODELLING

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.


(a)



(b)

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

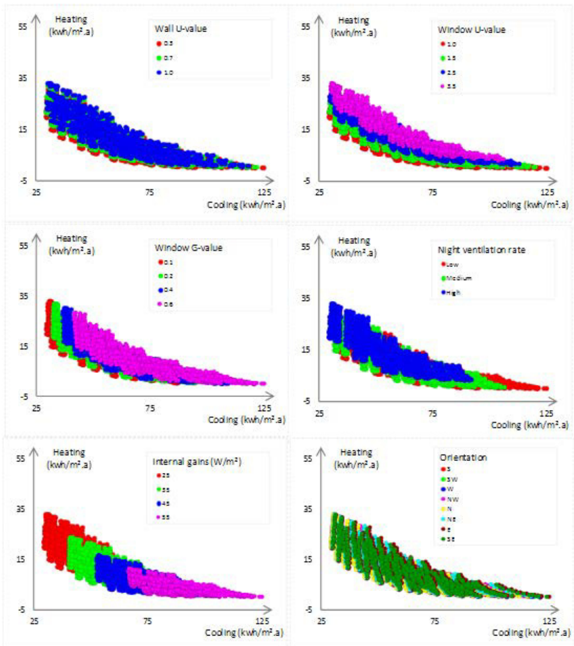


Figure 9 Sensitivity analysis for different variants in GIS (Top-left: wall U-value, top-right: window U-value, middle-left: window G-value, middle-right: night ventilation rate, bottom-left: internal gains, bottom-right: orientation)

- 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.

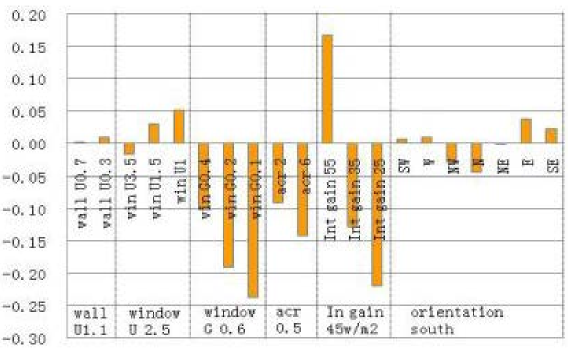


Figure 10 Variance ratios of annual energy consumption of single variant changes from base case.

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).

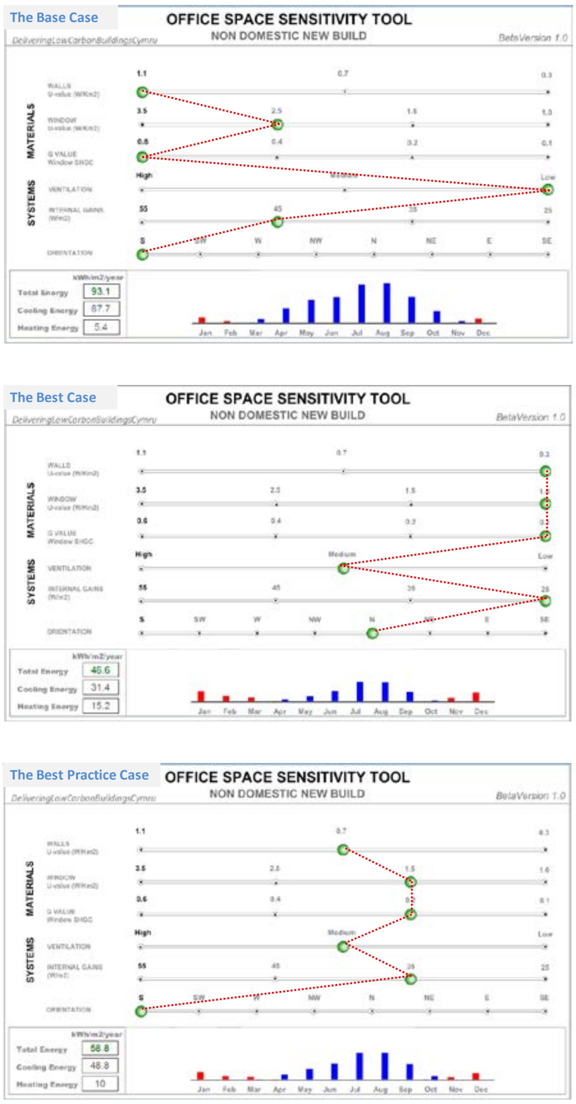


Figure 11 Sensitivity Tool set up for the base case (top), the best case (middle) and the best practice case (bottom).

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 w/m²***

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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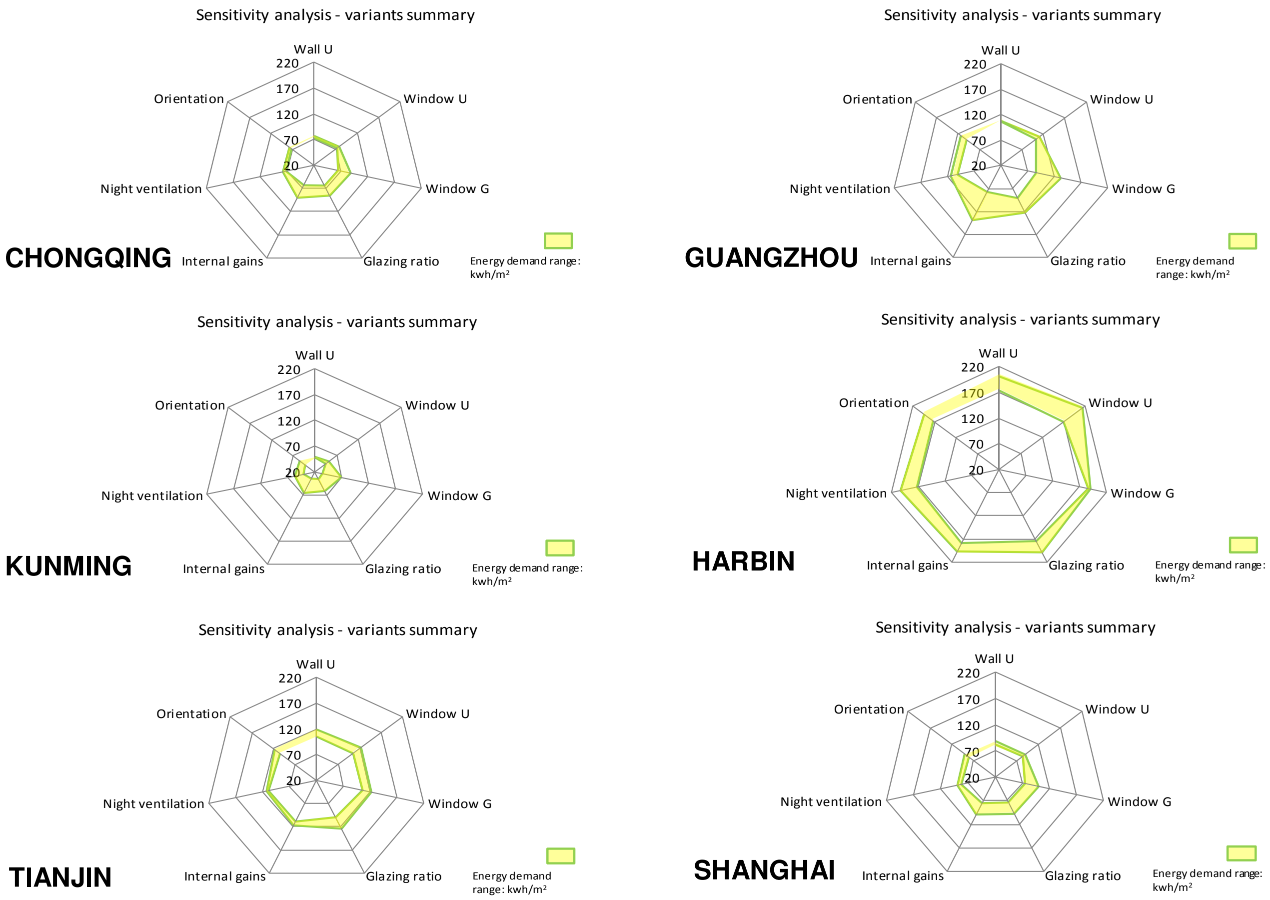

Figure 12 Analysis from 6 locations in china

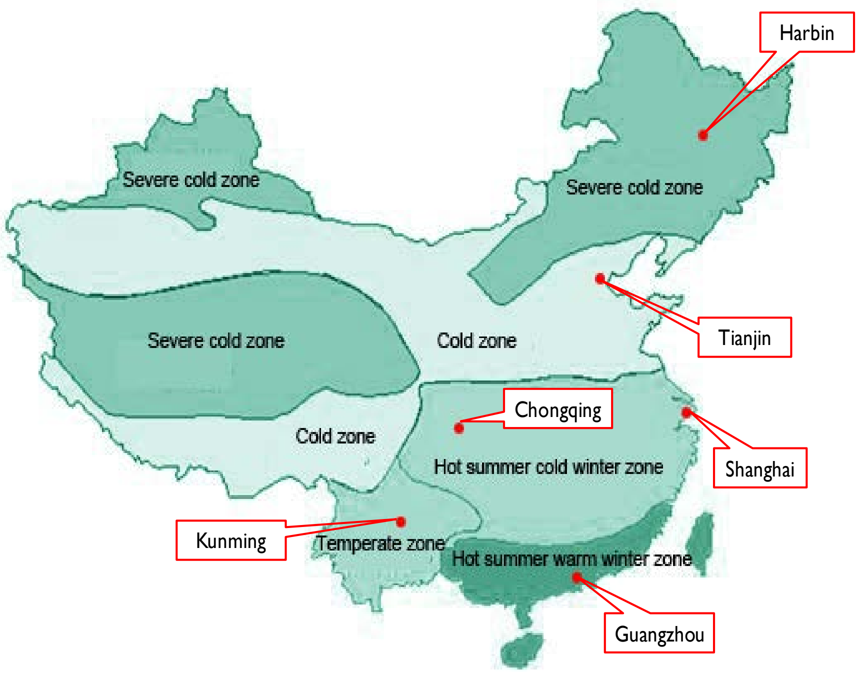

Figure 13 Locations of sensitivity analysis and climate zones in China.

Glossary

Building Research Establishment Domestic Energy Model (BREDEM)

Dynamic Simulation Modelling (DSM)

Energy and Environmental Prediction (EEP)

Engineering and Physical Sciences Research Council (EPSRC)

Geographic Information Systems (GIS)

Home Energy Conservation Act (HECA)

Housing and Neighbourhoods and Health Project (HANAH)

Lower Layer Super Output Areas (LSOA)

Medical Research Council (MRC)

Middle Layer Super Output Areas (MSOA)

Standard Assessment Procedure (SAP)

UK Energy Research Centre (UKERC)

Virtual Village (VirVil)

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