

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

Qian Li<sup>1</sup>, Phil Jones<sup>1</sup>, and Simon Lannon<sup>1</sup>

Welsh School of Architecture, Cardiff University,  
Cardiff, CF10 3NB, UK

### 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).

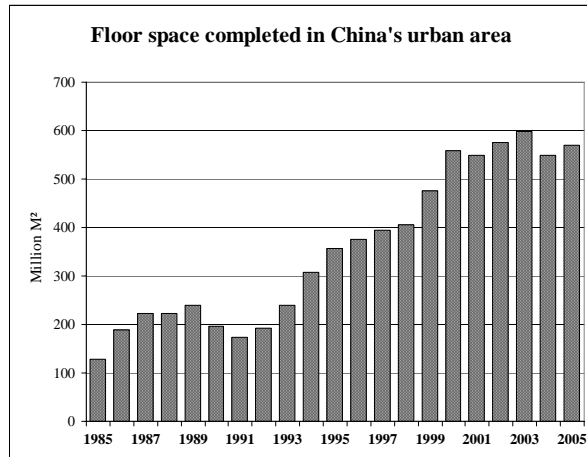


Figure 1: Floor space completed in cities

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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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.

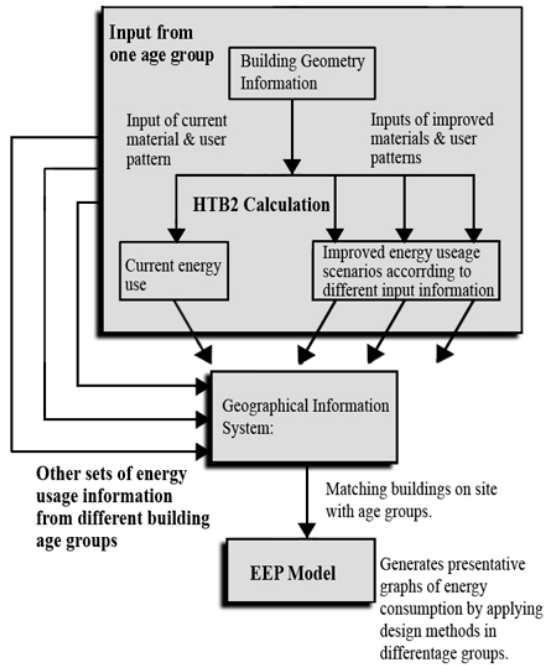


Figure 2: Data flow process of software combination

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<sub>2</sub> 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



Figure 3: Satellite map of site

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.

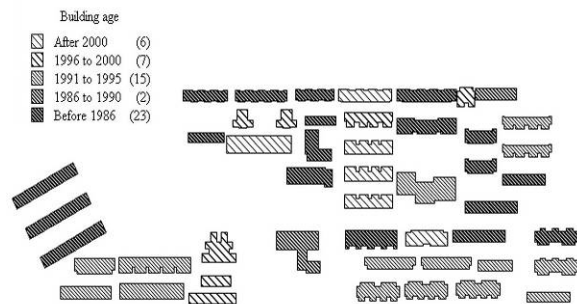


Figure 4: Residential Building Age Pattern of the Site

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<sup>2</sup>) located at south-west Xi'an

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,

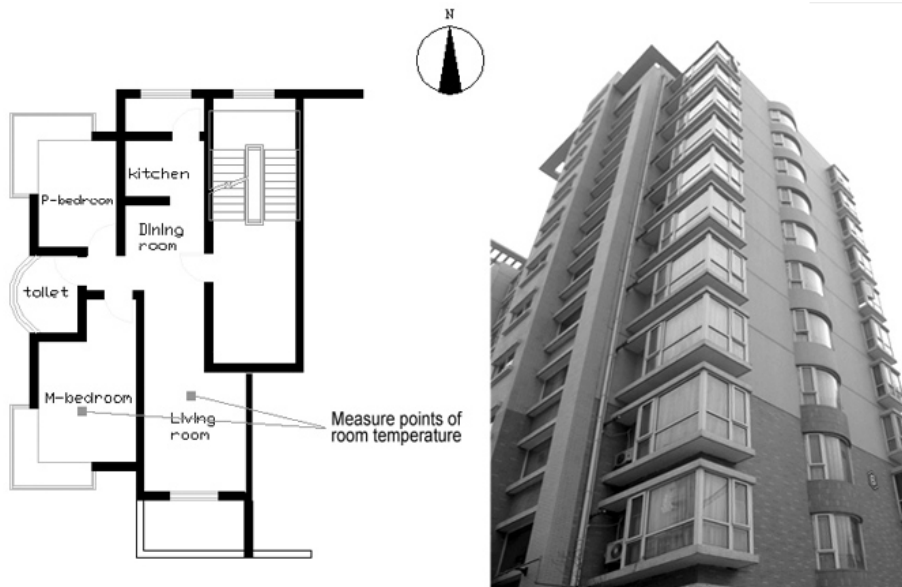


Figure 5: Flat plan and building appearance

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 glazing ratio is around 40%.

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.

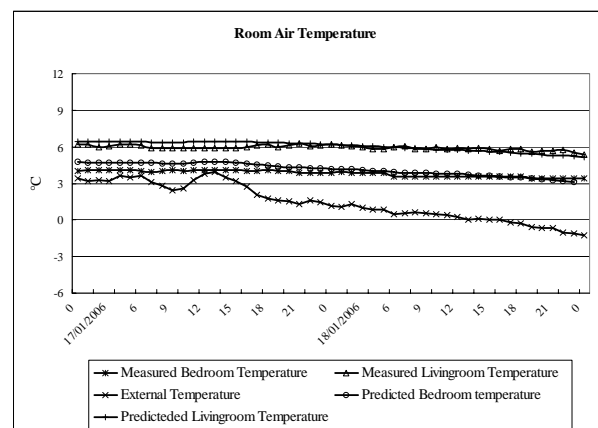


Figure 6: Compare of Predicted data with measurement

energy consumption of the investigated models was predicted. The seasonal weather data in Xi'an city was obtained from the Energy<sup>+</sup> 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<sub>2</sub> 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.

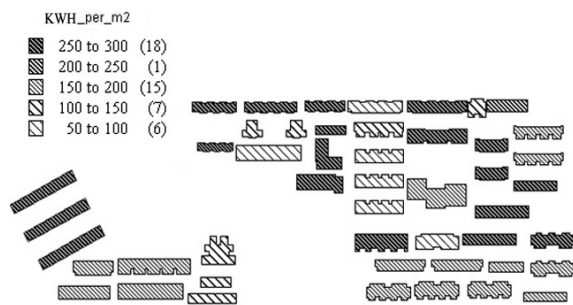


Figure 7: Thematic map of average energy usage

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<sub>2</sub> 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).

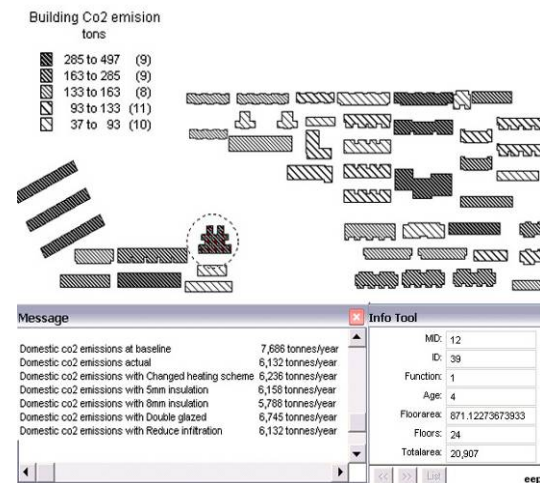


Figure 9: Annual carbon dioxide emissions by building



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

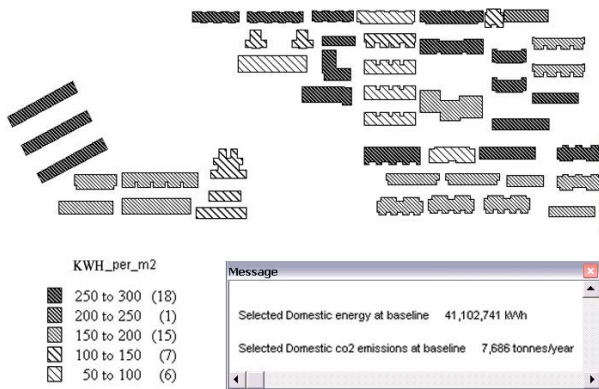


Figure 10: Presentation of energy consumption and CO2 emission

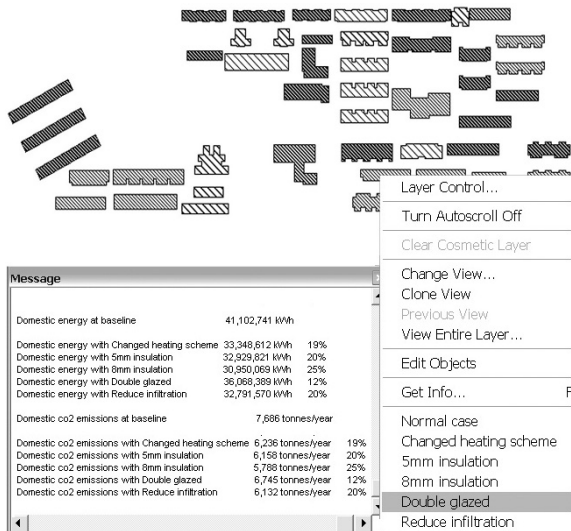


Figure 11: Energy consumption with double glazing fitted

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<sub>2</sub> 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.

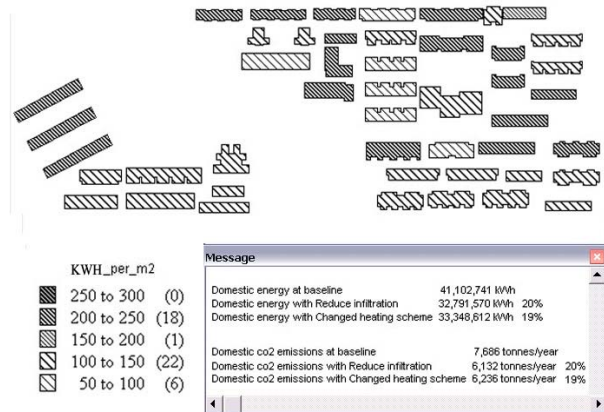


Figure 12: Improved energy efficiency

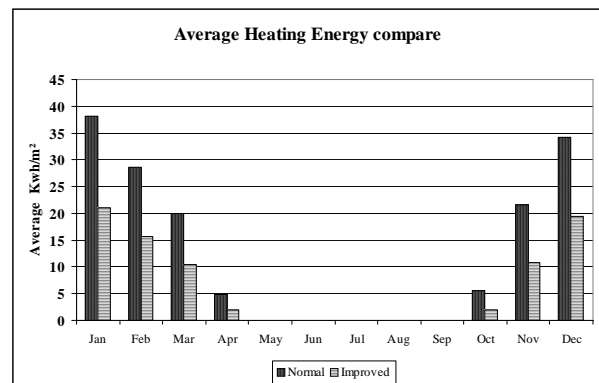


Figure 13: Comparison of heating energy

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 (KWEH/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 modification
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.

## REFERENCES

- Alexander, D. (1996). HTB2 User Manual. Cardiff, Welsh School of Architecture.
- Alexander, D. and P. Jones (1996). Heat Transfer in Buildings 2.0. Welsh School of Architecture: Thermal predictive model.
- China, State Environmental Protection Administration of China (2002). <Indoor Air Quality Standard>. China, GB / T 18883—2002.
- China's Bureau of Statistics. (2005). China Statistic Yearbook B. o. statistics, Chinese Statistic Publishing Company. 1: 915.
- CRIBE, Centre for Research in the Built Environment. (1999). EEP User Manual, Welsh School of Architecture.
- EnergyPlus Weather Data. (2006)  
<http://www.eere.energy.gov/buildings/energyplus/>
- EU Asia Pro Eco Project (2006). Sustainable Urban Housing: strengthening capacity in policy formulation and implementation in the city of Xi'an. Cardiff, Welsh school of architecture.
- Jones, P. J. and D. K. Alexander (1999). Modelling building performance. The 3rd International Symposium On Heating, Ventilation and Air Conditioning. Shenzhen.
- Li Liu & Tao, Y. (2004). "Low density housing and modern eco-technology." Architect 6: 28.
- Ma, Z. (2006). Dilemma in Real Estate, China Housing Industry Association.
- Marsh, A. (2004). Ecotect 5.5. Square One and Welsh School of Architecture: Building analysis application
- Ministry of Development. (2005). Guidance for Developing Energy Efficiency Residential and Public Architecture.
- Phil, J. and S. Lannon (2000). "Planning for a sustainable City: An Energy and Environmental Prediction Model." Journal of Environmental Planning and Management 43(6): 855-872.
- Qiu, B. (2006). China's High Energy Consume Architecture. People's Daily. Beijing.