Programme Area: Buildings

Project: Building Supply Chain for Mass Refurbishment of Houses

Title: Determining an energy modelling methodology to be used in the ETI Thermal Efficiency Project

Abstract:

Please note this report was produced in 2011/2012 and its contents may be out of date. This report provides a review & assessment of the various building modelling approaches used in the UK, France, Germany & USA. The objective being to provide a recommendation for the building modelling procedure to be used through the remainder of the OTEoEH project.

Context:

This project looked at designing a supply chain solution to improve the energy efficiency of the vast majority of the 26 million UK homes which will still be in use by 2050.It looked to identify ways in which the refurbishment and retrofitting of existing residential properties can be accelerated by industrialising the processes of design, supply and implementation, while stimulating demand from householders by exploiting additional opportunities that come with extensive building refurbishment.The project developed a top-to-bottom process, using a method of analysing the most cost-effective package of measures suitable for a particular property, through to how these will be installed with the minimum disruption to the householder. This includes identifying the skills required of the people on the ground as well as the optimum material distribution networks to supply them with exactly what is required and when.

Determining an energy modelling methodology to be used in the ETI Thermal Efficiency project

31st October 2010

EXECUTIVE SUMMARY

This document provides a recommendation for the energy modelling methodology to be used in the ETI Thermal Efficiency project.

An initial investigation of existing energy models of dwelling performance identified 26 models in use the UK, France, Germany, USA and Canada which may be of interest of the project. The models have been assessed against the requirements of the project, which were identified through a User Requirements exercise carried out by BRE.

The assessment of models recommends that the energy modelling methodology consist of:

- A stock model that uses a simplified energy model as its calculation engine.
- A simplified model for individual dwelling calculations (the same model as used in the stock model).
- A detailed simulation model (or models) for individual dwelling modelling in situations where such a model is necessary.

The assessment of the 26 models identified concludes that BREDEM (2009) is the most suitable energy methodology for the stock and simplified models, with the choice of detailed simulation models determined by specific questions and queries as required. It is also recommended that, within the main model, alternatives to some empirically determined BREDEM algorithms are considered as appropriate.

Determining an energy modelling methodology to be used in the ETI Thermal Efficiency project

Introduction

This document has been structured in two parts.

Part 1 summarises the main features of the models that were considered previously and were reported in deliverable 1.1.

Part 2 discusses the required functionality of the model(s) needed for the ETI thermal modelling programme, assesses the various models against these criteria, and thereby leads to some recommendations. This section of the report is based up detailed investigations of each of the modelling methodologies and an examination of the requirements of each methodology against the requirements of the project.

Part 1

Models of dwelling energy performance

An initial identification of models in use.

There follows an initial identification, and brief description, of the models employed in the UK, France and Germany for calculation of the energy performance of dwellings. Also identified and described are the EnergyPlus methodology developed in the USA, and the Canadian 'CHREM' model.

By identifying the models that are available this provides the starting point for the recommendation of a methodology to be used in the ETI-TE project, which is discussed in part 2 of this document.

The models which have been considered are listed below and are grouped by (principal) country of development:

UK:
BRE Domestic Energy Model (BREDEM)
Standard Assessment Procedure (SAP)
Simplified Building Energy Model (SBEM)
BRE Housing Model for Energy Studies (BREHOMES) *(Stock model)*
Energy Questionnaire (EnQuire) (S*tock model*)
IES VE Virtual Environment-Pro (VE-Pro)
Tas building Designer
DesignBuilder
Ecotect Analysis
ESP-r
The Community Domestic Energy Model (CDEM) (*Stock model*)
The UK Domestic Carbon Model (UKDCM) *(Stock model)*
Domestic Equipment and Carbon Dioxide Emissions (DECADE) *(Stock model)*
The Johnston Model *(Stock model)*
The Tina Fawcett Model *(Stock model)*
The DECarb model *(Stock model)*
The Domestic Energy Model for Scotland (DEMScot) *(Stock model)*

France:
Diagnostic de Performance Énergétique (DPE)
Réglementation thermique 2005 (RT 2005)
Simfast

Germany:
EnergieEinsparVerordnung (DIN 4108 and DIN4701)
EnergieEinsparVerordnung (DIN V 18599)
LeGep
PassivHaus Planning Package (PHPP)

USA & Canada:
EnergyPlus
CHREM

Models developed in the UK:

Name of model:
BRE Domestic Energy Model (BREDEM)
Ownership of model (and developer(s) if different):
Developed and owned by BRE. Development of the model is supported by the Department of Energy and Climate Change.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
Very widely used across the UK and in the Republic of Ireland. BREDEM is the basis of SAP (see below) and forms the core of the vast majority of modelling procedures used in the UK.
Brief summary of the methodology:
BREDEM is an easy to use, highly flexible model which outputs estimates of energy consumption by fuel. Within BREDEM it is possible to vary element U-values, heating system efficiencies, number of occupants, etc, and to account for increases or decreases from average usage of up to 20%. There are two versions of BREDEM currently in use. BREDEM-12 is the annual version of the model. BREDEM-8 is the monthly version of the model. [There is actually a third version, BREDEM-9, but this is more commonly known as SAP, which is a quite distinct tool intended for energy rating of dwellings (see below).] Both versions of BREDEM are simplified two-zone physics-based models producing predictions of energy use for space heating, water heating, lighting, appliances and cooking. The models incorporate some empirical features (such as the relationship between lights and appliance energy use and floor area and number of occupants) but the space heating calculations are based on an energy balance that takes account of all of the important physical factors. In the early 1990s the two models were extensively tested against measurements in actual dwellings using data that was collected in the 1980s and very early 1990s. They were also subjected to the same comprehensive tests that were then being applied to detailed simulation models. The various tests showed that, fed with the correct inputs, BREDEM was able to produce reliable predictions of energy use in actual dwellings. Moreover, its energy use predictions were essentially as good as those of detailed simulation models - although, of course, the simplifications made in BREDEM mean that sometimes a simulation tool would be required to address specific issues. However, a distinct advantage of BREDEM over simulation tools is its ease of use. It is anticipated that in the near future only the monthly version of BREDEM will be used (and will be known as BREDEM 2009, to emphasise its close alignment with SAP 2009 – see below).

Name of model:
Standard Assessment Procedure (SAP)
Ownership of model (and developer(s) if different):
Developed by BRE on behalf of the Department of Energy and Climate Change.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
Very widely used across the UK and in the Republic of Ireland. SAP 2005 is used for demonstrating compliance with the Building Regulations in England, Wales, Scotland and Northern Ireland. It is also used to produce the ratings that appear on Energy Performance Certificates for new homes. It is an energy rating tool, rather than an attempt to model actual consumption. SAP 2005 is shortly to be superseded by SAP 2009. SAP 2009 will be used for demonstrating compliance with the Building Regulations in England, Wales and Scotland from October 2010. It is expected that it will be used in Northern Ireland from April 2011. SAP 2009 uses a monthly calculation rather than the seasonal calculation used by SAP 2005. The respective specification documents can be downloaded from the BRE website: http://projects.bre.co.uk/sap2005/ http://www.bre.co.uk/sap2009/page.jsp?id=1642 There is also a reduced data version of SAP known as RdSAP (it is actually contained within the main SAP specification as an appendix, so it is not really a different version except in the sense that it provides a different way of specifying the model inputs). RdSAP is used for generating ratings for existing dwellings for Energy Performance Certificates (EPCs). RdSAP differs from the main SAP procedure by providing a specific methodology for assigning U-values of existing buildings (based on dwelling age and wall type), dimensions and other factors which cannot easily be measured for an existing building. EPCs will continue to be generated using SAP 2005 until 27 March 2011, but it is anticipated that they will be based on SAP 2009 thereafter.

Brief summary of the methodology:
SAP is a constrained version of BREDEM developed specifically to allow the comparison of dwellings on a consistent basis, independent of location and of the occupants and how they choose to use their home. Since it is a version of BREDEM, SAP follows the general methodology that has already been described above, although there are some small differences within the detail. However, it is important to recognise that SAP is a labelling tool, which means that there are some limitations on how it can/should be used. In particular, SAP calculations are for a notional average UK location rather than being specific to the actual dwelling location. A standard heating pattern is also assumed in all cases (unlike BREDEM in which the heating pattern can be varied at will, although the standard pattern is often used as a default). Similarly, assumptions regarding number of occupants (and, hence, the energy used for, and the gains from, water heating and lights, appliances and cooking) are based on the floor area of the dwelling rather than on the actual number of occupants. In addition to space heating and water heating, lighting use is included in SAP, but cooking and appliance use is not (except in the sense that the corresponding internal gains, which will affect the space heating requirements, are included). The principal output of the SAP procedure is the "SAP rating" which runs between 1 (very poor energy efficiency) and 100 (very high energy efficiency). This is based on the notional running cost of the home, normalised for floor area. SAP is also able to output CO_2 emissions for Building Regulations purposes, and the "Environmental Impact Rating" (EIR) which also runs on a scale between 1 and 100. SAP 2009 is being introduced because a monthly calculation should be better than a seasonal calculation for the very low energy dwellings that are being demanded by the Building Regulations as we approach zero carbon home standards. Recent comparisons between SAP 2009 and other models (including detailed simulation models) have been carried out by the Zero Carbon Hub and these have confirmed that SAP 2009 is appropriate for compliance purposes for such dwellings (subject to some concerns about the overheating procedures contained in the model which will need looking at further). SAP 2009 and BREDEM 2009 have been developed in parallel and so the two tools will be more closely aligned than was the case for previous versions.

Name of model:
Simplified Building Energy Model (SBEM)
Ownership of model (and developer(s) if different):
SBEM is a software tool developed by BRE that provides an analysis of a building's energy consumption. It was developed by BRE for the Department for Communities and Local Government. The latest version of the SBEM tool and its accompanying user interface, iSBEM, can be downloaded free of charge from the dedicated National Calculation Method website at http://www.ncm.bre.co.uk/
Extent of usage (i.e. which countries are the model used in, how widely are they used):
SBEM is effectively the non-domestic equivalent of SAP (SBEM is used to demonstrate compliance with Building Regulations for buildings other than dwellings. SAP is used for the same purpose, but for dwellings only) and it is therefore very widely used in the UK. SBEM is used for non domestic buildings in support of the National Calculation Methodology (NCM) and the Energy Performance of Buildings Directive (EPBD). The tool helps to determine CO_2 emission rates for new buildings in compliance with Part L of the Building Regulations (England and Wales) and equivalent Regulations in Scotland, Northern Ireland, the Republic of Ireland and Jersey. It is also used to generate Energy Performance Certificates for non-domestic buildings in construction, for sale or let. A variant of the SBEM tool is now in use in Cyprus and developments are underway for other countries, initially in Europe.
Brief summary of the methodology:
SBEM calculates monthly energy use and carbon dioxide emissions of a building given a description of the building geometry, construction, use and HVAC and lighting equipment. It was originally based on the Dutch methodology NEN 2916:1998 (Energy Performance of Non-Residential Buildings) and has since been modified to comply with the recent CEN Standards. Details of the calculation method, the algorithms used and the assumptions made are provided in the SBEM Technical Manual, available from the download page of the National Calculation Method website at http://www.ncm.bre.co.uk/. SBEM makes use of standard data contained on associated databases and available with other software. The purpose of SBEM and its interface iSBEM is to produce consistent and reliable evaluations of energy use in non-domestic buildings for Building Regulations Compliance and for Building Energy Performance Certification purposes. Although it may assist the design process, it is not primarily a design tool. It does not calculate internal temperatures, for example. And it should not be used for system sizing.

Name of model:
BRE Housing Model for Energy Studies (BREHOMES)
Ownership of model (and developer(s) if different):
Developed and owned by BRE. Development of the model is supported by the Department of Energy and Climate Change.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
BREHOMES is a model of the energy use of the GB housing stock based on aggregating individual (BREDEM-based) calculations of energy use for a large number of categories of dwellings (over 1,000). The first implementation of the model was produced in the mid-1980s. Since then, it has been continuously developed and used to inform a wide variety of Government Departments, the Energy Saving Trust, the Statistical Office of the European Communities and the International Energy Agency. The model has been widely accepted as a valuable policy advice tool.
Brief summary of the methodology:
BREHOMES works at a highly disaggregated level, and the BREDEM-based calculations at the core require a wide variety of data, including the following: • Areas of wall, roof, floor, windows, doors, their thermal characteristic (U-value) • Heating system characteristics (fuel type and efficiency) • Demand temperatures, heating patterns, number of occupants • Number of dwellings in each of the above categories • External temperatures and solar gains This information has been obtained from a variety of information sources, such as: • Housing and Construction Statistics • Family Expenditure Survey • English House Condition Survey (EHCS), now English Housing Survey (EHS) • Market research data • Information on lights and appliances from DECADE (Domestic Equipment and Carbon Dioxide Emissions) and MTP (Market Transformation Programme) The stock segmentation in the model is detailed and reflects the categories available in the market research data and the EHCS/EHS. The segmentation is by dwelling type (e.g. semi, detached, terrace), age, tenure and by whether centrally heated or not. For each of these categories there is information fed into the model on heating systems by type / fuel and on insulation of the key elements (wall, roof, windows) and of the hot water tank (if present). The “bottom up” calculations of the model are reconciled with the “top down” statistics from the Digest of UK Energy Statistics by adjusting input parameters (most notably the demand temperatures). The reconciliation of “bottom up” and “top down” data has been undertaken each year and this provides information that is valuable for documenting trends over time. This is a particular strength of BREHOMES which is key to many of the analyses undertaken with the model and its outputs.

Name of model:
Energy Questionnaire (EnQuire)
Ownership of model (and developer(s) if different):
Developed by BRE on behalf of DECC.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
Widely used by Local Authorities across England.
Brief summary of the methodology:
EnQuire is a computer software package used by Local Authorities to report against National Indicator 187. This indicator specifically examines the number of households in receipt of Income Related Benefits (IRBs) with a SAP rating below 35 or above 65, although the software is also able to report on all households (whether or not they are in receipt of an IRB). Inputs into the software are survey returns from householders, obtained via a postal or telephone survey, which ask a set of core questions on energy efficiency. The EnQuire software then performs a SAP calculation using default values for required variables not directly collected by the survey (e.g. wall area, floor area, window area). The required defaults are provided by data from approximately 1,300 dwelling archetypes derived from the English House Condition Survey (EHCS). The archetypes used are produced by subdividing by dwelling type, age, size and tenure. In addition to calculating SAP ratings (and the metrics required for the NI187 return) the software also estimates CO_2 emissions and a breakdown of the presence of heating systems in each These additional outputs are provided to assist Local Authorities in targeting refurbishment and improvement schemes and to understand the pattern of energy use in the housing stock.

Name of model:

IES VE Virtual Environment-Pro <VE-Pro>

Ownership of model (and developer(s) if different):

The IES environment was developed and is owned by Integrated Environmental Solutions Limited, UK. Some of its individual modules are based on earlier work undertaken by other developers. For example, the ApacheSim module is based on Apache building energy simulation software developed at Oscar Faber Applied Research.

Extent of usage (i.e. which countries are the model used in, how widely are they used):

IES <VE-Pro>is one of the most popular general purpose building energy simulation tools. The tool has a very extensive user base in the UK, as well as many users throughout Europe, North America and Asia. Its target audience is wide ranging and includes building services engineers and architects, local government, building managers as well as its widespread use in university research and teaching applications.

Brief summary of the methodology:

IES <VE-Pro> is a Windows platform-based integrated environment of tools. The program is based on several programming languages such as Visual Basic, C++ and Fortran 7.

The software environment incorporates several modules covering a range of building analysis functions. For input, geometrical building data can be imported from a range of CAD systems via customised links or DXF files into the <VE> 3D building model module. Input of other data is managed via graphical interfaces and is supported by extensive databases.

For energy/carbon calculations, the main modules are:

- ApacheSim: A dynamic thermal simulation for energy/carbon modelling
- ApacheCalc: A heat loss/gain calculations tool that uses CIBSE procedures to determine design heating/cooling loads
- ApacheLoads: A design heating/cooling loads calculations tool that uses ASHRAE Heat Balance Method
- ApacheHVAC: A modelling tool for conventional/advanced HVAC systems, operation and control that works in conjunction with ApacheSim
- MacroFlo – A modelling tool for bulk airflow analysis for passive/hybrid ventilation system design and simulation that works in conjunction with ApacheSim

ApacheSim is the main dynamic thermal simulation module used for thermal design and energy simulation related to buildings. The module uses a method based on first-principles mathematical modelling of building heat transfer processes, driven by real weather data.

Within ApacheSim, simulation is carried out in an iterative non-linear systems solution approach. Thermal conditions can be traced at user-selected intervals with a minimum time step of one minute. ApacheSim allows for multiple zones, calculating for up to a maximum of approximately 5000 zones in a single building model.

IES <VE-Pro> produces a comprehensive range of energy/carbon, lighting calculation and solar shading related outputs. These are viewed using a built-in viewer that allows the presentation of output in both tabular and graphical form. Outputs may also be exported in a variety of formats to other software packages.

Name of model:
Tas Building Designer
Ownership of model (and developer(s) if different):
The tool was developed by Cranfield Institute. It is owned by Environmental Design Solutions (EDSL) Ltd, which was established in 1989 to commercially develop it. Full feature trial versions of the software and various licensing options for tool use are available
Extent of usage (i.e. which countries are the model used in, how widely are they used):
The Building Energy Software Tools Directory lists usage including 250 user sites, which are mainly based in Europe, Canada and Australia. The tool has been in use for commercial purposes for over 20 years and is commonly taught as part of the undergraduate and graduate program curriculum for building services engineering and architectural design related degrees.
Brief summary of the methodology:
Tas is a C++ language Microsoft Windows platform software package, primarily used for the thermal analysis of buildings. The software structure is module-based, where some functions (such as compliance calculations) are carried out via dedicated program macros. The main program modules are: • Tas Building Designer: a dynamic building simulation tool with integrated natural and forced airflow • Tas Systems: a HVAC systems/controls simulator, which may be directly coupled with the building simulator. It performs automatic airflow and plant sizing and total energy demand • Ambiens: a 2D CFD package which produces a cross section of micro climate variation in a space • Airscoop Builder: a modelling utility incorporated into newer versions of the software The Tas Building Designer module includes a graphical interface CAD-linked 3D modeller, a building simulator and a results viewer. Input is supported by a comprehensive set of databases that cover materials, constructions, climate data and occupation schedules. In addition to a built in database of plant/systems characteristics, manufacturer's performance data can also be input. Simulation within Tas Building Designer is carried out in an iterative non-linear systems solution approach. Both building and plant are simulated on hourly time steps through a complete year of weather data. Tas Building Designer allows for multiple zones, where there is no maximum number of zones that can be included in a single building model. However, in the case of models containing more than 300 zones, a simulation run time error can often occur. The tool produces a comprehensive range of energy/carbon results including compliance outcomes and loads calculations. In addition to a built-in results viewer, these outputs can be exported to other spreadsheet and word processing packages.

Name of model:
DesignBuilder
Ownership of model (and developer(s) if different):
DesignBuilder was developed and is owned by DesignBuilder Software Ltd. The software was first launched in 2005. Free fully functional evaluations can be downloaded and various licensing options exist.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
The tool has a rapidly growing user base, which is thought to exceed 200 (April 2006). The target audience for the software includes consulting engineers, architects, academic research and teaching departments. The user base is distributed around the world, with local support in the US, UK, Italy, China.
Brief summary of the methodology:
DesignBuilder was developed as the first comprehensive graphical user interface to EnergyPlus. The software is a Windows XP and 2000 platform based program that is based on several programming languages including C++ (geometric engine), Visual Basic (dialogs) and Fortran (EnergyPlus simulation engine). As a user-friendly graphical interface to Energyplus, an OpenGL solid modeller is used for geometry input. Other building information uses data templates. Since the Energyplus calculation engine is used, calculations are performed using the heat balance based approach as the solution technique for building thermal loads. Analysis is performed using both sub- hourly user-definable time steps (thermal zones and the environment) and automatically varied time steps (thermal zones and HVAC systems). The simulation engine Energyplus allows for multiple zones, however an increased number of zones can considerably increase calculation run time. More recent versions of the software feature additional Building Information Modelling interoperability and integrated 3-D CFD calculations linked to EnergyPlus. A comprehensive range of simulation data can be displayed graphically or in tabular form in annual, monthly, daily, hourly or sub-hourly intervals. Output data can also be exported in a range of formats to spreadsheet and custom reports.

Name of model:
Ecotect Analysis
Ownership of model (and developer(s) if different):
Ecotect Analysis was developed at the Centre for Research in the Built Environment at Cardiff University. Commercial ownership was transferred from Square One Research to Autodesk Inc, which offers various licensing options and free annual student versions of the software.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
Ecotect has a large worldwide user base of over 2000 individual licenses holders. The software is taught at approximately 60 universities in Australia, UK and USA. Its user base includes architects, engineers, environmental consultants and building designers.
Brief summary of the methodology:
Ecotect Analysis is a complete environmental multi-function design tool which includes solar, thermal, lighting, acoustic and cost analysis functions. The software is a windows platform C++ language program, which can also run on Mac OS under Virtual PC. The tool aims to facilitate environmental performance analysis from the earliest conceptual design stages. Input is undertaken through a 3D CAD modelling interface that also imports 3DS and DXF files. An integrated comprehensive scripting engine provides direct access to model geometry and calculation results. This allows models to be completely interactive and self-generative. Ecotect provides a range of thermal performance analysis options. The software itself uses the CIBSE Admittance Method to determine internal temperatures and heat loads, which is considered to be less suitable in situations where there are large sudden variations in parameters. In this case, analysis is performed using hourly time steps. The tool itself allows for multiple zones, and does not impose limits on the number of zones used in a building model. In addition, the export facility can be used to access a range of more technical and focussed analysis engines, such as EnergyPlus or ESP-r. In this case, the analysis can be performed in smaller time steps; however some of these tools do have zone number limitations.

Name of model:
ESP-r
Ownership of model (and developer(s) if different):
ESP-r was developed by Energy Systems Research Unit at the University of Strathclyde. As a subject of sustained developments since 1974, the tool has been freely available under a GNU Public License (GPL) since 2002. Various support agreements with the developer exist and the source code is also accessible to users.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
The tool is widely used with hundreds of users including engineers, researchers, architects, energy consultants, primarily located in Europe and Asia. The tool has an active user community and mailing list to address technical issues.
Brief summary of the methodology:
ESP-r is a general purpose simulation environment which supports an in-depth appraisal of the factors which influence the energy and environmental performance of buildings. As a multi-platform tool that uses C and FORTRAN (F77 or F90) programming languages, ESP-r compiles with most Unix and Linux compilers, GNU compilers and MINGW. The tool comprises a central Project Manager around which are arranged support databases, a simulator, various performance assessment tools and a variety of third party applications for CAD, visualisation and report generation. Constructional and operational attribution is achieved by selecting products and entities from the support databases and associating these with the surfaces and spaces comprising the problem. ESP-r is based on a finite volume, conservation approach. Here, a problem is transformed into a set of conservation equations (for energy, mass, momentum, etc.) which are then integrated at successive time-steps in response to climate, occupant and control system influences. Building and flow simulations can be undertaken at frequencies of one minute to one hour and HVAC system simulations range from fractions of a second to an hour. The tool allows for multiple zones, where the latest version (v11.9) allows the generation of Integrated Performance Views for a maximum of 72 zones in a single building model. Output analysis modules are used to view the simulation results, undertake a variety of performance appraisals and explore the interactions between assessment domains. ESP-r is compatible with AutoCAD and Ecotect and ESP-r models can be exported to other assessments tools such as TSBI3, Radiance and EnergyPlus. Results data can be exported to other analysis and graphing tools. ESP-r has been extensively validated and is highly flexible, powerful and robust, however its use requires a higher degree of expertise and understanding of thermo-physical processes in buildings, environmental systems and controls.

Name of model:
The Community Domestic Energy Model (CDEM)
Ownership of model (and developer(s) if different):
The model was developed by Firth et al. at the Department of Civil and Building Engineering, Loughborough University, Loughborough, UK.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
CDEM is a policy advice tool used for research purposes to explore potential routes to reduce CO_2 emissions in dwellings and operates at the national, regional and local authority scale. The tool is open structure and was used to undertake the modelling work and field studies for domestic buildings by the CaRB Consortium Project (Carbon Reduction in Buildings) domestic research team in the UK.
Brief summary of the methodology:
CDEM is a physically based bottom-up model of the energy use of the UK housing stock developed to explore potential routes to reduce CO_2 emissions and predict the emissions of the existing English housing stock. It can be used to model the national housing stock for the UK as well as for separate regions, local authorities, cities, and other sub-national areas. The CDEM model consists of two main components: a house archetype calculation engine and a core building energy model. The house archetype calculation engine defines the characteristics of 47 individual house archetypes chosen primarily to capture the variation in space heating (the largest proportion of domestic energy consumption). The archetypes are derived from combinations of built form type and dwelling age. The model uses a weighted average stock transformation method that takes into account the proportional relevance of each component, rather than treating each component equally. There are 27 primary input parameters to CDEM, obtained from various sources such as: • The 2001 English House Condition Survey (e.g. average total floor area, space-heating system-type distribution) • BREDEM-8 Default tables and calculation algorithms (e.g. set-point temperature for space heating) • Allan and Pinney standard dwelling types (building geometry) • Market Transformation program (e.g. average fraction of low-energy lights) • SAP 2005 • Census 2001 data (number of dwellings in the 2001 English housing stock) • The Meteorological Office (monthly external temperatures and solar radiation) The model uses local sensitivity analysis, linearity and superimposition tests to quantify the impact of input parameters on output uncertainties. In addition to calculating CO_2 emissions, the model also calculates annual energy consumption based on the BREDEM model. Both annual energy consumption and CO_2 emissions are calculated.

Name of model:
The UK Domestic Carbon Model (UKDCM)
Ownership of model (and developer(s) if different):
The model was developed by Boardman et al. as part of the 40% House project undertaken at the Environmental Change Institute (ECI), Oxford University.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
The model is a policy advice tool that is freely available and is widely used in UK academic studies.
Brief summary of the methodology:
UKDCM is a physically based bottom-up model of the energy use of the UK housing stock developed as part of the 40% House project. The model is essentially a numerical model of energy flows, taking into account all the sources of heat gain and heat loss in a stock of dwellings whose characteristics change through time and was developed to investigate how 60% savings could be achieved in the UK residential sector. The UKDCM uses detailed housing data from the English House Condition Survey (EHCS) and the corresponding surveys of housing in Northern Ireland and Scotland to form the basis of a stock model of UK housing. A highly disaggregated housing stock approach which can be manipulated through a large set of operator-defined data points is used. This comprises over 20,000 dwelling types by 2050 and utilises a weighted average stock transformation method. In addition to the housing condition surveys, data for the model is obtained from such sources as: • DECADE (Lights and appliances) • Government Actuary's Department (GAD), ODPM (population, household size) • UK Climate Impacts Programme (climate) • UKBORDERS GIS (UK regions) • ForeSight (socio-economic context) The base year for the model is 1996 Dwellings are defined by geographical areas, age classes, types of construction, number of floors, tenure and construction method, with each type given an appropriate weighting to describe the overall carbon and energy profile for a given scenario. UKDCM calculates monthly demand for space heating using BREDEM heat flux approach.

Name of model:
Domestic Equipment and Carbon Dioxide Emissions (DECADE)
Ownership of model (and developer(s) if different):
Environmental Change Institute (University of Oxford).
Extent of usage (i.e. which countries are the model used in, how widely are they used):
Widely used in the UK, often forming inputs into other models (e.g. UKDCM and BREHOMES).
Brief summary of the methodology:
DECADE is not in itself a model of the housing stock, but instead models electricity use in the UK domestic appliance sector developed with the intention of assessing the impact of a range of energy efficiency policies in the UK. The DECADE model is a vintage stock model that uses a bottom-up modelling approach. Electricity consumption is based on the number of households and average consumption by each appliance in an average household. A highly disaggregated approach is used, based on the categorisation of mains electrical domestic appliances. These are assigned to one of seven major categories, each subdivided into further sub-categories with over 13,000 data cells covering 26 major appliance groups. The appliances included in the DECADE study follow the conventions adopted by both the Building Research Establishment and the Electricity Association. The approach ensures that all domestic electricity consumption is included either in DECADE or in the BRE's BREHOMES model and data is organised to allow the examination of electricity consumption trends at more than one level. Data for the DECADE model was collected and analysed for the period 1970 to 1994 and projected forwards to 2020. Much of the data that was required was either unavailable (i.e. had never been collected) or was limited to a single (national) average figure. Sources of data include: • The Electricity Association (unit energy consumption (UEC) of appliances) • The LEEP Billsavers project (Meter reading to supplement UEC data) • The 1991 census (demographic data, household numbers)

Name of model:
The Johnston model
Ownership of model (and developer(s) if different):
The model was developed as part of a PhD thesis research project undertaken by D. Johnston/Leeds Metropolitan University.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
The model is a policy advice tool, it however has limited usage since it is only available to the developers.
Brief summary of the methodology:
The Johnston model is a physically based bottom-up model of the energy use of the UK housing stock, developed to explore the technological feasibility of achieving CO_2 emission reductions in excess of 60% within the stock by 2050. The model is constructed around two components: a data module and a BREDEM based energy and CO_2 emission model. A selectively disaggregated approach was adopted to allow the relevant sectors of the UK housing stock (i.e. those that dominate domestic energy use and CO_2 emissions) to be disaggregated to a greater degree than others. Data input into the model is simplified through the use of only two 'notional' dwelling types (pre- and post-1996) to represent different categories of dwellings and uses a 1996 base year. The model uses a weighted average stock transformation method. Both annual energy consumption and CO_2 emissions are calculated. Input data for the model was obtained from various sources, which include: • Office for National Statistics (population projections) • DETR (mean household size data) • 1996 English House Condition Survey (details of the state of the existing housing stock) • DECADE (projections of the future energy demand of lights and appliances) • BRE (S-curves used to project the likely uptake rate and ownership of various insulation measures) In instances where data was not readily available, this information was generated internally, either by manipulating the existing data sets, or by devising the data based upon the results of previous modelling studies or practical case studies.

Name of model:
The Tina Fawcett Model (TF)
Ownership of model (and developer(s) if different):
The model was developed as part of a PhD thesis research project undertaken by T.Fawcett/UCL.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
The model is a policy advice tool, it however has limited usage since it is only available to the developers.
Brief summary of the methodology:
The Tina Fawcett model is a variant of the Johnston model, recreated from available data and descriptions to investigate the role of social and lifestyle change in increased demand for energy services and assess its impact on projected technical improvement scenarios. The model is a physically based bottom-up model of the energy use of the UK housing stock that uses essentially the same two components (a data module and a BREDEM based energy and CO_2 emission model) and the selectively disaggregated approach described by Johnston. The input data for the Tina Fawcett model is obtained from the same sources listed in the Johnston Model and are as follows: • Office for National Statistics (population projections) • DETR (mean household size data) • 1996 English House Condition Survey (details of the state of the existing housing stock) • DECADE (projections of the future energy demand of lights and appliances) • BRE (S-curves used to project the likely uptake rate and ownership of various insulation measures) For some original input data that was not included in the description of the Johnston model, assumptions were made by the author, consequently it is recognised that input data between the two models varies slightly.

Name of model:
The DECarb Model
Ownership of model (and developer(s) if different):
The model was developed by Natarajan and Levermore at the University of Bath
Extent of usage (i.e. which countries are the model used in, how widely are they used):
The model is a policy advice tool that is freely available.
Brief summary of the methodology:
DECarb is a physically based bottom-up model of the energy use of the UK housing stock. The model incorporates a forecasting technique to account for future dwelling types and is used for exploring future transformations in the UK housing stock. Two classes of data were used to build DECarb: future climate data - monthly average climate data from the UK Climate Impacts Programme's future climate data scenarios (UKCIP02) and current housing stock data for the UK (such as changes to appliance use, building stock thermal properties, occupant comfort and planning regulations). These were combined with novel algorithms to enable long term carbon-sensitive decisions for policy makers. The model is highly disaggregated and uses a relational data set to delineate 8064 unique combinations for 6 historical age class bands. The model uses 2-step iterative stock transformation method, with a 1996 base year. Data set consists of 6 files (1 file for each of 6 age classes), while these data are composed of 7 variables (dwelling type, insulation characteristics, etc). DECarb calculates CO_2 emissions and annual energy consumption, which is based on a modified version of the BREDEM model. Input data for the model was obtained from various sources, which include: • UK Climate Impacts Programme's future climate data scenarios-UKCIP02 (average climate data) • 1996 English House Condition Survey supplemented by house condition survey data for other countries in the UK (housing stock data) • DECADE (energy consumption of lights and appliances)

Name of model:
The Domestic Energy Model for Scotland (DEMScot)
Ownership of model (and developer(s) if different):
Developed by Cambridge Architectural Research (CAR) for the Scottish Government.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
Used by Scottish Government for policy analysis. Freely available to download for use by researchers.
Brief summary of the methodology:
DEMScot is a physically based bottom-up model of energy use developed to allow policy makers to see the effect of different strategies for upgrading Scottish housing by estimating the potential CO_2 savings and financial costs involved (Scottish Government Social Research 2009). The model calculates the energy consumption, costs and climate change emissions from different dwelling types representing the whole Scottish building stock based on enhanced versions of the BREDEM work sheet methodology set out in SAP2005 revision 2 (2008, worksheet version 9.82). The DEMScot model has five components: • A building stock database • A building physics model • Factors under occupant control • Parametric analysis, • An embodied energy component. In describing the stock, a highly disaggregated approach was used. For this model a number of parameters considered to have the most impact on the performance of buildings types were chosen. The selection of different house types was based on six key categories, each with a number of sub-categories. This categorisation gives 43,200 possible types of existing dwelling types, although not all are included in the records of the 2006 Scottish House Condition Survey (SHCS). Input data for the model was obtained from various sources, which include: • Scottish House Condition Survey (Scottish housing data) • Scottish Government (Scottish weather data) • Cambridge Econometrics (2009 fuel cost data) • SAP2005 (calculations for lighting, small power and cooking elements)

Models developed in France:

Name of model:
Simfast
Ownership of model (and developer(s) if different):
The tool has been developed by EDF R & D (the core model is owned by EDF) and an external software developer EDF under contract (Society Arobas Technologies).
Extent of usage (i.e. which countries are the model used in, how widely are they used):
Exclusively used by EDF in support of its domestic customers.
Brief summary of the methodology:
SIMFAST is based on a dynamic simulation model that calculates hourly energy consumption, CO_2 emissions and cost of energy consumption by modelling dynamic behaviour of heating/cooling systems, building types, occupant behaviour and weather. The model is mainly used for the estimation of energy consumption for residential customers and requires only a minimal number of parameters to run the model; most of which are often available from the customer and hence allow for fast simulation of the model. These parameters include: dwelling age; construction type; and thermal losses. Simfast can also be adapted for use in the planning and design process of renovation projects for new heating and air conditioning proposals. The model is capable of taking into account possible consumption patterns and personal comfort levels as well as evaluating the impact of changes to weather patterns and customer energy tariffs. It also has the ability to modify data in a short time period and has high precision of estimates if all input parameters are known. The modelling is based on physical equations of heat transfer to the envelope; average yield for systems; occupancy scenarios (temperature set point, the presence of occupants, etc); scenarios of internal input; and meteorological data provided by Meteo France every three hours and for 75 meteorological stations. The model makes some assumptions about residential usage including control systems, lighting and occupancy and has been validated by EDF R&D.

Name of model:
Diagnostic de Performance Énergétique (DPE)
Ownership of model (and developer(s) if different):
The tool has been developed by an engineering study, TRIBE and commissioned by the DGUHC (Direction générale de l'urbanisme, de l'habitat et de la construction) and ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) in the framework of a working group representing the major energy companies, BET, the controlling bodies and trade unions of building professionals.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
The DPE (ECD) is an Energy Performance Diagnostics to be performed in France by qualified and certified design officers in housing. It is valid for 10 years (if no renovations are undertaken in the meantime) and is presented as a certification of energy performance for each real estate transaction (sales from 07/2006 and rentals from 07/2007).
Brief summary of the methodology:
DPE is a diagnostic energetic performance tool which is a static model with two parameters that creates one simulation for one year and evaluates energy consumption, CO_2 emissions and cost & energy classification of a dwelling. It was developed based on the French Thermal Regulation requirements of 1989. The imprecision of the static method can be compensated by the use of accurate data and complementary dynamic analysis. The core model uses a calculation method that is a relatively simple calculation of heating with: $$Cch = Bch \times Ich$$ Where: *Ich* = coefficient of heating (efficiency) *Bch* = heating (kWh)

Name of model:
Réglementation thermique (RT 2005 : Thermal regulation 2005 tool)
Ownership of model (and developer(s) if different):
The RT 2005 is the French thermal regulation tool designed for residential projects and has been developed by CSTB (Centre Scientifique et Technique du Bâtiment).
Extent of usage (i.e. which countries are the model used in, how widely are they used):
This tool creates a thermal regulation performance for a property and is generally used for customers wanting to sell their home in France. It is implemented for the use of property sales so as to encourage builders and contractors to build more energy efficient and environmentally-friendly homes.
Brief summary of the methodology:
The RT2005 tool is a dynamic model to evaluate the energy consumption of a property during the design phase (including envelope and energy systems) and has a time frame for calculations of one hour. The model calculates energy consumption, CO_2 emissions and the energy cost and classification of a dwelling. RT2005 calculates the energy level of the building by splitting into several thermal areas, groups and user patterns. It takes into account the 'bioclimatic demands' of the building (heating. cooling, lighting etc.) and indoor temperature requirements to calculate the primary energy consumption. The model requires input of all parameters of the building including physical characteristics (window type, construction type, orientation) as well as present systems in the property (heating, cooling, lighting, DHW, ventilation and energy production). The calculation involves: 1. Characterization of the physical attributes of each component of the building by the intermediary of computational algorithms (e.g. operation of a boiler, a heat pump, etc...) 2. Some parameters must reflect an average behaviour observed in France and so a number of ratios are also computed. Meteorological data provided by Meteo France also contributes to the calculations used in the model, such as: • France is divided into eight climate zones • Creation of hourly meteorological measurements, calculated on the basis of measurements from the last 15 to 20 years • Types of data used are: air temperature, wind speed, direct normal radiation. The occupancy scenarios used in the model such as temperature set point and the presence of occupants, are defined in an area of building. The same building may contain several zones.

Models developed in Germany:

Name of model:
EnEV (EnergieEinsparVerordnung) 2009, calculation according to the German energy performance of buildings standard DIN 4108 and 4701 (compare to the EnEV 2009, according to DIN 18599 below).
Ownership of model (and developer(s) if different):
The EnEV 2009 (according to DIN 4108 and 4701) is a calculation method approved, owned and developed by the German Government. It is calculated using a variety of software tools and forms part of the **EnergieEinsparVerordnung law in Germany.**
Extent of usage (i.e. which countries are the model used in, how widely are they used):
This calculation method has been refined steadily since 2001 when first established. As these software programs are quite cheap or even free of charge, they are widely used, although this method cannot be used to calculate high energy efficient buildings with an annual heating demand smaller than 40 kWh /m²a or certain retrofit buildings. Future plans of the German Government will probably establish the calculation method according to DIN V 18599 as the only permitted method.
Brief summary of the methodology:
The dynamic calculation method features a simplified one-zone model mainly used for domestic buildings of an annual heating demand range between 40 and 90 kWh/m².   The method allows the assessment of the major building energy parts such as energy need, primary energy, U-values and heat losses.   Buildings are calculated according to their outer measurement volumes and designs, the outer surfaces and construction materials of all parts (walls, windows, etc), thermal bridges and all heat losses through these. Additionally the heating components and ventilation are being assessed.   None of the two major requirements (heat loss through transmission and the technical quality) of the calculated building are allowed to exceed the values for a reference building of the same geometry, building floor space and alignment with a given technical reference design (sustainable building construction).   The calculations are based on one standardised climate and standardised user profiles, using calculation time steps of the months of one year.   Some of the software programs which utilise this method allow adapting these standardised data, or provide regional weather data for more realistic additional calculations. Most of the software tools provide a simple additional calculation of costs and payback period for retrofit actions. Some of the tools also provide a calculation of air pollutants.

Name of model:
EnEV (EnergieEinsparVerordnung) 2009, calculation according to the German energy performance of buildings standard DIN V 18599 (compare to the EnEv 2009, according to DIN 4108 and 4107 above).
Ownership of model (and developer(s) if different):
The EnEV 2009 (according to DIN V 18599) is a calculation method approved, owned and developed by the German Government. It is calculated using a variety of software tools and forms part of the **EnergieEinsparVerordnung law in Germany.**
Extent of usage (i.e. which countries are the model used in, how widely are they used):
This holistic calculation method is widely used for all kind of buildings following the European guidelines. As it is quite complex, most of the users are specialised architects, engineers and building physicians. Future plans of the German Government will probably establish the calculation method according to DIN V 18599 as the only permitted method.
Brief summary of the methodology:
The dynamic calculation method is a holistic and complex methodology implementing European requirements for the energy performance of buildings. It features a multi-zone model (mostly up to 16 zones) implementing complex configurations of heating, ventilation technologies and also air conditioning and lighting and allows the assessment of all building parts including heat loss, energy need, energy use and primary energy. A very detailed input of building components, zones, shading, heating, ventilation, cooling and lighting systems, etc allows detailed and competent outputs of all relevant parameters. According to the law, standardised climate data and user profiles have to be applied but nearly all of the software tools provide additional regional weather data and adaptation of the standards. As the method according to DIN V 18599 is very complex the use of an approved software tool is essential and it is important to have a closer at the most common tools: Tools that allow alterations to the standards are Bautherm 18599(BMZ-Software), Energieberater Plus 18599 (Hottgenroth Software), EnEV Plus (WEKA MEDIA), EnEV-PRO 2009 (VISIONWORLD), EnEV Wärme & Dampf (Rowa Soft), IPB 18599 High End (Heilemannsoftware) and Wärmeschutznachweis für Hochbauten aller Art DIN V 18599 (Ingenieurbüro M. Hanneforth), the latter provides also an index of thermal bridges. It would be impossible to perform a calculation without use of one of these tools. Tools that provide additional to the alterations of the standards construction costs and economical calculations are BKI Energieplaner (BKI), ennovatis EnEV+ (ennovatis), EPASS-HELENA (ZUB Kassel e.V.), EVA 18599 (Ingenieurbüro Leuchter), EVEBI (Envysis W. Schöffel) and Energieeffizienz für Gebäude DIN V 18599 (SOLAR-COMPUTER), both integrating indexes of thermal bridges. The tool Dämmwerk Bauphysik Software (Kern Ingenieurkonzepte) provides alterations of the standards and additional calculations for noise protection, fire protection, room acoustics and thermal bridging. **All tools calculate air pollutants most of the tools (except BKI, WEKA and IPB) provide CAD-interfaces of varying quality.** One of the tools includes assessment of noise and fire protection and room acoustics.

Name of model:
LeGep
Ownership of model (and developer(s) if different):
SirAdos
Extent of usage (i.e. which countries are the model used in, how widely are they used):
This tool is mainly used by specialised architects, consultants and engineers because of its wide range of calculations. According to the developer there are currently over 100 tools in use around Germany used mainly for the design of new built buildings, taking into account the future life cycle. For existing buildings LEGEP assists in the decisions on refurbishment operations and long term, sustainable management of buildings.
Brief summary of the methodology:
LEGEP is a tool for integrated life-cycle analysis. The dynamic calculation tool is based on both versions of the EnEV 2009 (described separately) or the European Standard EN 832. Additional more customised calculations are based on detailed weather data and user profiles. An integrated database contains the description of all elements of a building (based on DIN 276); their life cycle costs (based on DIN 18960) and the final report EU-TG4 LCC in construction. All information is structured along life cycle phases (construction, maintenance, operation (cleaning), refurbishment and demolition. The environmental assessment comprises the material flows (input and waste) as well as an effect oriented evaluation based on ISO 14040 – 43. It can be combined with other SirAdos tools for tender, cost calculation or construction management and provides data output in all common formats (GAEB 2000, MDI, RTF, etc). There are several input options depending on the state of the planning process varying from given elements to detailed constructions. At each level a complete evaluation can be made and documented automatically. Output of LEGEP: at each phase a complete, interrelated set of cost, energy, mass-flow and environmental indicators. The number of indicators, which are displayed, can be chosen from the environmental indicators (Green house potential 100 years, Acidification potential, Photochemical Ozone creation potential, Ozone depletion potential, Eutrophication potential, primary energy consumption renewable and non-renewable, Ecoindicator etc.). It is possible to show all or certain indicators for each life cycle phase (new construction, operation, cleaning, maintenance, refurbishment, demolition) of the building. The main advantage of this tool is its holistic approach including environmental, economical and life-cycle calculations.

Name of model:
PHPP (Passivhaus Planning Package)
Ownership of model (and developer(s) if different):
Passivhausinstitut W. Feist, R. Pfluger, B. Kaufmann, J. Schnieders, O. Kah
Extent of usage (i.e. which countries are the model used in, how widely are they used):
This tool is widely used in Germany and other countries because of its low cost and exact calculation method. It is mainly used for the calculation of very low energy buildings, new build and also for retrofit projects. It can be used for domestic and commercial buildings.
Brief summary of the methodology:
The dynamic precise calculation tool was developed to design and build buildings with very low energy consumption. The PHPP is a Microsoft Excel based tool and therefore simple to use. It features a one-zone model providing worksheets for U-values, thermal bridging, heating energy balances, distribution, supply, electricity and primary energy demand. The time steps can vary from monthly to annually. The methodology is easy to understand for the user as all calculations can be seen, and the biggest advantage is to be able to understand how certain changes affect the building. The methodology is based on European standard EN 832. Regional climate data (international) is implemented. It is essential to calculate thermal bridging exactly or to change the code for a standardised assessment. Exact air infiltration heat loss measurement can be included as well as assessment of electrical lighting and appliances. Its main advantage is that any aspect of calculation can be adapted for special uses and the tool can be expanded easily by adding own worksheets.

Models developed in the USA & Canada:

Name of model:
Energyplus
Ownership of model (and developer(s) if different):
EnergyPlus was developed by Lawrence Berkley National Laboratories (LBNL) for the U.S. Department of Energy (USDOE) in 1996. The tool was first released for public use in 2001. Several licensing options that address the needs of both commercial and non-commercial uses exist. These allow for various degrees of ownership of derivative works and redistribution rights.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
EnergyPlus is a very widely used tool. It is estimated that over 85,000 copies of EnergyPlus have been downloaded since it was first released. Its target audience includes mechanical, energy and architectural engineers, consulting firms, US federal agencies and research universities and laboratories.
Brief summary of the methodology:
Energyplus is a building energy analysis and load simulation program based on the main features and capabilities of two predecessors, BLAST and DOE-2. The software is a multi-platform Fortran 2003 language program tool, based on a modular system structure. Since the programming code is open source, this enables public inspection, revision and the development of further modules. Energyplus also links to other simulation environments such as WINDOW5, COMIS (airflow model), and SPARK to allow more detailed analysis of building components. Although Energyplus utilises ASCII text -based input and output files, the program structure facilitates the development of more user-friendly (and domain-specific) third party interfaces (such as a plug-in for Google Sketchup). Additionally, the ASCII output files can be adapted into spreadsheet form for further analysis. For energy performance calculations, both the building systems simulation and the heat balance-based zone simulation modules are integrated with the simulation manager. The heat balance based approach is used as the solution technique for building thermal loads. An integrated, simultaneous solution approach where the building response and the primary and secondary systems are tightly coupled is used and allows iteration to be performed when necessary. Analysis is performed at sub- hourly user-definable time steps for the interaction between the thermal zones and the environment. Automatically varied time steps are used for interactions between the thermal zones and the HVAC systems to ensure solution stability. The tool allows for multiple zones; however an increased number of zones can considerably increase calculation run time. Energyplus is considered to be highly accurate and is validated through a comparatively extensive testing approach (the results of which are made available on the relevant web site). Weather data (in the epw format) for more than 1250 locations are available.

Name of model:
Canadian hybrid residential end-use energy and emissions model (CHREM)
Ownership of model (and developer(s) if different):
CHREM was developed at Dalhousie University in Canada as part of a PhD thesis research project undertaken by L. Swann. The CHREM is a research tool that was specifically developed to assess the impacts of new technologies when applied to the CHS.
Extent of usage (i.e. which countries are the model used in, how widely are they used):
The model primarily deals with the Canadian residential sector. The CHREM will be made available in the public domain for research use. Access to the CHREM can be obtained by contacting the author (Lukas.Swan@Dal.Ca).
Brief summary of the methodology:
The principal objective of the model was to develop a new energy consumption and GHG emissions model of the Canadian Housing Stock (CHS). The model batch processes a database of nearly 17,000 real house descriptions that statistically represent the CHS and employs a hybrid modelling approach that builds upon the strengths of different modelling methods: The bottom-up method (the statistical component): this employs a calibrated neural network (NN) and is used to account for the effect of occupant behaviour on the DHW and AL end-uses. The bottom-up engineering method (the engineering component): is used to enable the capacity for modelling alternative and renewable energy technologies. Estimation of space heating and cooling loads is accomplished using the high-resolution building performance simulation package ESP-r (see above). Together, these are used to estimate the energy consumption of the major end-use groups: Domestic appliances (e.g. refrigerator, stove) & lighting (AL) Domestic hot water (DHW) Space heating and cooling. With the use of 2 dedicated quad-core dual-processor computers, it is estimated that model run time requires a few days of simulation.

Part 2

Recommendation of energy modelling methodology

Determining a energy modelling methodology for the project.

It will be clear from Part 1 that the models that have been considered cover a wide range of types from simplified energy balance models to detailed simulation models, and from individual building energy models to models of the entire stock.

This emphasises that different types of model are required for different purposes and that there is no single type of model that is suitable for all purposes.

In principle, one of the existing stock models could be used for the ETI work. However, such models do tend to be designed to address the specific needs of the programmes of work from which they spring. Thus, it is clearly highly likely that there will similarly be a need to structure a model around the specific needs of the ETI programme and so it would be better to develop something new, nonetheless still applying the same basic modelling approaches.

The choice of core model, therefore is principally determined by the requirements of the users of the model, which must be considered alongside the practical feasibility of the achieving these requirements.

In order to identify the requirements of users, BRE undertook an extensive user requirements exercise. The results of this exercise are laid out in the detai8led model functional specification which accompanies this report. The final requirements list is replicated below:

Requirements of the core system (TE WP 1):

- System must be accessible to third party developers
- System must consider heating of space and water, lighting, appliance and cooking energy use
- System must validate inputs to ensure that they are feasible, throwing up flags or ‘alarm bells’ to the user attempting to enter unfeasible combinations of inputs
- System must determine the outcomes of refurbishment
- System must output annual consumption
    - By fuel
    - By end use
- System must output annual consumption per square metre floor area
- System must output annual fuel savings
- System must output annual running costs (pre- & post-improvement)
- System must output annual energy production (μDE technologies)
- System must output annual CO_2 emissions (pre- & post-improvement)
- System must output energy usage for gas and electricity (and other fuels) separately
- System must output the EPC ratings pre- and post-improvement
    - Requires a parallel run in SAP mode
    - Requires that system must take inputs on orientation, thermal mass, overshading, etc.

- System must simulate alternative intervention scenarios for improvements to individual dwellings
- System must model several alternative improvement scenarios simultaneously
- System must identify the most appropriate improvement package for any particular dwelling
- System must take account of element underperformance, household comfort take and the rebound effect
- System must prioritise the cost effectiveness of packages of interventions
    - E.g. the cost per tonne of CO_2 saved
- System must allow for the variation of occupant behaviour by the actor (user or other system)
    - Heating behaviour
    - Take-up behaviour (e.g. who chooses a new boiler? The occupant or the central heating engineer?)
    - Degree of comfort take or rebound effect
- System must allow custom schedules of costs to be input
- System must allow custom fuel prices to be entered
- System must consider embodied carbon
- System must model new, as yet uninvented products
- System must flag information about the proposed solution for any dwelling modelled e.g.
    - Unachievable
    - Difficult
    - Likely to overrun on costs
    - Disruption level (decant, impact on household)
    - Wall thickness issues (e.g. impact on space standards or boundary line)
    - Supply chain limiting factors (this applies more to stock level system)
    - Potential difficulties of being in a mixed tenure block
- System must allow the specification of a particular product (having a given set of characteristics) or of a non-specific solution that is of a given specification.
    - This means having some default products to select
        - e.g. CWI: U-Value = 0.60
- System must allow for the variation of assumptions about carbon intensities of fuels
- System must be capable of running in ‘simple’ or ‘sophisticated’ modes (the former having much of the customisation functionality disabled)

Requirements of the stock system (TE WP2):

- System must model scenarios out to 2030 (based on UKERC 2050 scenarios) to predict impact of
    - appliance development,
    - buildings improvement,

  - DE penetration,
  - fuel price changes
- System must identify 'prime candidates' for improvement and the grouped locations of these types
- System must allow some user-specified variables to be changed (e.g. energy price and penetration rates)
- System must show scope for carbon savings aggregated to national level for each nation of the UK.
- System must represent uncertainty in the output (e.g. carbon saved, consumption averted, cost (risk))
- System must evaluate the potential benefits of micro-DE technologies (current and emerging)
- System must evaluate the potential benefits of building energy services controls
- System must evaluate the potential benefits of TE technologies (current and emerging)
- System must output capital cost of upgrades (for stock: individual dwelling installation costs will be an input)
- System must look at different fuel mixes
- System must look at different energy uses
- System must consider different categories of occupant (prudent, large consumer, etc.)

With these requirements in mind, the functionality of each of the models described in Part 1 has been examined by UCL, BRE, EDF R&D and Luwoge.

The initial conclusion of this examination is that no 'off the shelf' solution is able to satisfy all of these requirements. None of the 26 models identified is able to provide what is needed as it currently stands. It seems prudent, however, to build on the work already done in producing each of these pre-existing models where it is possible to do so. We are therefore required to produce a specific model for the project, making use of the most appropriate methodology.

A second observation from the list of requirements is that many of them are not directly influenced by the choice of core energy methodology (for example, the estimation of cost of improvements is a secondary element of the model to run alongside the energy component).

One of the principal constraints on the energy methodology is that it must be suitable for both individual and stock modelling. What is required from a stock model, however, often differs from what is required from an individual building model. This is simply because when modelling the entire stock there are necessarily more limitations on the data that is available than there would be when considering an individual dwelling. For example, the survey data that forms the basis of stock models is unlikely to contain detailed dimensions and precise thermal characteristics for the various elements of the different types of dwelling (this is the case of all data that is available). In general, stock modelling has to use typical dwelling archetypes and thermal characteristics have to be deduced from limited information (sometimes, for example, dwelling age might be used to ascribe a suitable form of wall construction, and hence an appropriate u-value).

Two distinct types of individual dwelling models were identified in Part 1 of this report: detailed simulation models, and simplified models. Detailed simulation models generally required detailed inputs, whereas simplified models do not. The additional details required for detailed simulations also result in a longer model runtime than for simplified methodologies. Given the limited resolution of stock level data, there are likely to be significant problems in trying to embed a highly detailed simulation model within a stock model. There would be considerable difficulties in defining all of the necessary inputs to a simulation model given the limited data and a very real danger of making serious mistakes in the process. Even if these problems could somehow be overcome, the resulting runtime of the model is likely to be excessive. Only one example of an embedded detailed simulation model was identified. This is the Canadian CHREM stock model, which embeds the ESP-r simulation within a model of the Canadian stock as a whole. The runtime of a UK version of this model was, however, considered to be too long (estimated at a few days per run) for this project.

Similar considerations also apply when considering the modelling of individual buildings, although to a much smaller extent. It has been well established that simplified models are often just as good as simulation models in predicting the annual, or monthly, energy use of individual dwellings[1]. So it makes sense to use a simplified model in many cases. However, this is not always the case. For example, any technology for which a short time step assessment of the energy implications would be required (such as micro CHP) ideally needs to be considered using a detailed simulation model using a time step of an hour or less. Of course, a simplified model could potentially be developed to replicate what a simulation model would produce in such cases by calibrating it against such a model. Nonetheless, there would always be a need for the detailed modelling - for each and every type of technology that fits into this category of requiring short time step calculations.

It therefore, follows from the above that what is needed for the ETI programme is:

- A stock model that uses a simplified energy model as its calculation engine.
- A simplified model for individual dwelling calculations (the same model as used in the stock model).
- A detailed simulation model for individual dwelling modelling in situations where such a model is necessary.

Having established these basic pre-requisites of the modelling methodology, each modelling methodology was examined in turn. This comparison is summarised in the following tables. The tables aim to capture just the key information for each of the models rather than all aspects considered as part of the assessment process.

[1] For example, the simplified BREDEM model has been extensively compared against detailed simulation models – e.g. "BREDEM: Testing monthly and seasonal versions against measurements and against detailed simulation models" Dickson, C et al. Proc. CIBSE A: Building Serv. Res. Technol. 17(3) 135-140 (1996)

Summary table 1 - Individual building models reviewed for ETI thermal efficiency project

Model name	Type (detailed simulation or simplified)	Widely used?	Track record in use for modelling entire stock?	Comments	Recommended?
BRE Domestic Energy Model (BREDEM)	Simplified	Yes	Yes. Used by almost all stock models that have been developed in the UK.	As a simplified energy model it has some limitations but it has been extensively validated. Simple to use and widely employed in stock models.	Yes (but perhaps needs to be supplemented by a detailed model for specific individual building calculations)
SAP	Simplified	Yes	No.	A labelling tool. Intended only for comparing dwelling energy performance rather than for energy calculations. Used for energy performance certificates and for Building Regulations. The parent model is BREDEM. Not suitable for stock modelling purposes (except in situations where it is the distribution of SAP ratings within the stock that is of interest).	No
SBEM	Simplified	Yes	No	A labelling tool. Intended for comparing building energy performance (for buildings other than dwellings) rather than for energy calculations - but may still be suitable for energy calculations. In principle, it can be used for dwellings (but generally it is not). Used for energy performance certificates and for Building Regulations compliance purposes.	Possibly
IES Virtual environment pro	Simulation	Yes	No	A comprehensive tool that might be suitable for individual detailed building modelling tasks within the ETI project. Not intended for stock modelling purposes (if used for such purposes run-times would very likely be excessive)	Yes (as a detailed model for specific individual building calculations)
Tas Building Designer	Simulation	Yes	No	A comprehensive tool that might be suitable for individual detailed building modelling tasks within the ETI project, although as its name suggests it is really intended for design purposes. Not intended for stock modelling purposes (if used for such purposes run-times would very likely be excessive)	Possibly (as a detailed model for specific individual building calculations)
Ecotect Analysis	Simulation	Yes	No	Ecotect Analysis is a design tool. It is not really intended for more general energy modelling purposes, such as modelling of a stock of dwellings.	No
ESP-r	Simulation	Yes	Limited (see CHREM below)	Comprehensive but requires significant expertise to be used effectively. Not intended for stock modelling purposes (if used for such purposes run-times would very likely be excessive).	No
Design Builder (EnergyPlus)	Simulation	Yes	No	A comprehensive tool that might be suitable for individual detailed building modelling tasks within the ETI project. Not intended for stock modelling purposes (if used for such purposes run-times would very likely be excessive). However, it has successfully been used for some "multiple building" calculations, so limited usage for such purposes within the ETI project may be feasible.	Yes (as a detailed model for specific individual building calculations)
Diagnostic de Performance Énergétique (DPE)	Simplified	Yes	No.	A labelling tool. Intended only for comparing dwelling energy performance rather than for energy calculations. Used for energy performance certificates in France. Not suitable for stock modelling.	No
Réglementation thermique (RT 2005)	Simulation	Yes	No.	Developed by CSTB for Building Regulation compliance purposes. Essentially a tool for the design phase rather than for more general energy modelling purposes such as modelling of a stock of dwellings.	No
Simfast	Simulation	No (only used by EDF)	No	Developed by EDF as a tool to advise their customers regarding the energy savings from different renovation options. A detailed simulation tool that is able to run using just some basic information from the customer (presumably using various inference procedures to provide the required detailed data relevant to each simulation). Not intended for, or used for, stock modelling purposes.	No
EnergieEinsparVerordnung (DIN 4108 and DIN4701)	Simplified	Yes	No	A calculation procedure required by law in Germany for new dwellings or for renovation of existing dwellings (likely to be replaced with DIN V 18599). Does not include lights and appliances or cooking. Not suitable for stock modelling.	No
EnergieEinsparVerordnung (DIN V 18599)	Simplified	Yes	No	A calculation procedure required by law in Germany for new dwellings or for renovation of existing dwellings. Does not include lights and appliances or cooking. Not suitable for stock modelling.	No

Summary table 2 - Stock models reviewed for ETI thermal efficiency project

Model name	Type (detailed simulation or simplified)	Widely used? (1)	Individual building model employed	Main source of stock data used by the model	Comments	Recommended (2)
BREHOMES	Simplified	Yes	BREDEM	EHCS (uses data from each year as it becomes available - 2008 data is the most recent used)	The first bottom up model of the energy use of the national housing stock introduced in the mid-1980s. Other models listed below have subsequently used similar approaches.	Yes
The Community Domestic Energy Model	Simplified	Yes	BREDEM	EHCS (2001data base year)	Used to undertake the modelling work and field studies for domestic buildings by the CaRB Consortium Project (Carbon Reduction in Buildings).	Yes
UKDCM	Simplified	Yes	BREDEM	EHCS (1996 data base year) (and similar data for Scotland and Northern Ireland)	The model was developed by Boardman et al. as part of the 40% House project undertaken at the Environmental Change Institute (ECI), Oxford University.	Yes
DECADE	Simplified	Used by other stock models. Was also further developed for incorporation in Defra's Market Transformation Programme.	Not applicable - models energy use of lights and appliances only	Census data, together with Electricity Association and other data form the basis of the model	Not a stock model of the type required for the ETI work	No (but the outputs are nonetheless relevant to the stock model that is to be developed for the ETI project)
The Johnston model	Simplified	No	BREDEM	EHCS (1996 data base year)	The stock disaggregation is greatly simplified in this tool	No
The Tina Fawcett Model	Simplified	No	BREDEM	EHCS (1996 data base year)	The same reservations as apply to the Johnston model (on which it is based)	No
The DECarb model	Simplified	Yes	BREDEM	EHCS (1996 data base year)	Developed at the University of Bath as a policy advice tool and freely available	Possibly
DEMScot	Simplified	Yes - but only for Scotland thus far	"enhanced SAP"	Scottish House Condition Survey (but could be generalised to use data better representing the UK as a whole)	Use of SAP is a concern but the approach used could equally be based instead on the more suitable BREDEM ("enhanced SAP" may mean that this is effectively the case)	Possibly
EnQuire	Simplified	Yes - but only by local authorities	SAP	Uses EHS data.	Not a stock model of the type required for the ETI work	No
Canadian hybrid residential end-use energy and emissions model (CHREM)	Simulation	No	ESP-r	Canadian stock level data (CSDDRD)	Estimated two-day runtime for model. Still in development	No

Notes:

(1) "Widely used", here means that the model has been used extensively in academic studies and/or policy advice activities, not that the model has a wide user community (the individual models tend to be specific to the developers and to specific studies)

(2) A new stock model will most likely need to be produced for the purposes of the ETI project. Thus, "recommended" here means that the modelling approach can be recommended rather than the stock model itself.

It may be observed from the stock models table that almost all of the considered models make use of BREDEM (the BRE Domestic Energy Model). Furthermore, almost all are based around data from the EHCS (the English House Condition Survey, now known as the English Housing Survey or EHS). There is thus a very strong initial precedent here for building on what has been done in the past and producing a stock model that similarly makes use of BREDEM and is based around the EHCS data and other stock condition data.

BREDEM's suitability as an individual building model, as well as the core of a stock model, has been demonstrated quite extensively in comparisons with simulation models and with measurements made in actual dwellings. Of course, there is nothing particularly special about BREDEM as such. It uses exactly the same principles as many other models (essentially the principles that are to be found in EN832 and subsequent similar European Standards). So, for example, the German PassivHaus Planning Package could be considered to be as equally applicable as BREDEM. However, a key consideration is the fact that BREDEM has over many years been carefully tailored to the energy use characteristics of UK households and dwellings which makes it uniquely well suited to this project. For this reason alone it makes sense to use it in preference to any other similar model.

It should be noted that in recent years an updated and improved version of BREDEM has been developed (although the specification is not yet published) and it would be sensible to use this new version. This is a further reason why it would be better to develop a new stock model, as obviously none of the existing stock models use this latest version of BREDEM.

There are, of course, downsides to using BREDEM. It is hoped, however, to draw on the techniques used in the alternative modelling techniques in order to reduce and remove these disadvantages.

One disadvantage to using BREDEM for this project is the use of empirical algorithms based upon average consumption of particular groups, for example in the calculation of the volume of hot water used. A key objective of the ETI project is to accurately model all energy usage, and these algorithms may be too much of a simplification for this project. Therefore, suitable alternative non-BREDEM techniques will be sought as available and appropriate. Concerns have also been expressed that BREDEM is often used under very rigid heating regimes, which can be very different to the times and heating extent actually used. While this is not in itself an attribute of BREDEM (which, in fact, allows for modelling of flexible patterns of use) it is important for this project to use BREDEM appropriately and to attempt to match to actual patterns of use, rather than those pre-determined by the modellers. All of this is, of course, ultimately dependent on suitable data being available which will allow the introduction of these new techniques and algorithms.

Concerns have been also expressed that the prevalence of BREDEM as the core modelling in energy models in the UK may lead to the propagation of errors. Considerable reassurance can be gained, however, in that BREDEM has been successfully validated against dynamic models, and is fundamentally based upon basic thermodynamic principles which can be considered proven. The 'twin-track' approach of using a more detailed simulation model alongside the simplified energy model should also allow some further validation of the BREDEM results to be produced by this project.

Although BREDEM is suitable for individual dwelling calculations it has to be recognised that there will be certain, short time step, calculations (and possibly other calculations as well) for which a more detailed tool will be needed for the ETI programme.
Simplified tools also exist which produce hourly outputs, such as the French SIMFAST methodology (which was demonstrated to the wider modelling team, as part of the assessment, by EDF R&D). The project will attempt to learn from and utilise these techniques as required.

Very specific and/or detailed dynamic performance issues may also require the use of a full building simulation tool as another parallel model. No specific recommendation of simulation tool has been made here. There are a number of tools that appear to be potentially suitable in their current form, and it seems likely that the ultimate choice of tool will be determined by the specifics of the questions which need to be answered. The table above suggests that there are probably three likely contenders – IES Virtual Environment pro, Tas Building Designer and Design Builder (Energy Plus).

Summary of recommendations:

- Develop an individual and a stock model that is aligned with the updated (2009) version of BREDEM and is based around house condition survey data.
- Attempt to incorporate novel algorithms as appropriate for the more empirically based components of the BREDEM methodology.
- For certain individual dwelling calculations for which a more detailed approach is needed it will be necessary to use an hourly time step model or a full simulation model.