EcoShopping - Energy efficient & Cost competitive retrofitting solutions for Shopping buildings

SEVENTH FRAMEWORK PROGRAMME

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Appendix 9.

Building performance assessment tools

EcoShopping

1 Building performance assessment tools

Existing buildings tend to have change in use, and unexpected faults or malfunctions over time. These problems often result in significant deterioration of the overall system performance, inefficient operation and unacceptable thermal comfort conditions. In a sustainable building retrofit, building performance assessments are used to benchmark building energy use, identify system operational problems, and find energy conservation opportunities. In the last two decades, the research and development in building performance assessment tools has been very active. This is reflected in the fact that a set of building rating tools are in the public domain, such as LEED, BREEAM, CASBEE, HKBEAM, Green Star, etc. These rating tools provide a framework on how to evaluate and improve building energy and environmental performance. Although these rating tools vary in scope, criteria, structure and format, the rating process is usually conducted via benchmarking the assessed building against a set of prescribed quantitative and qualitative performance indicators (PIs) of diverse objectives. Through examination of the difference between the PIs of the building assessed and the targeted PIs, the performance of the building can be quantified. The following five systems are currently the most popular, influential and technically advanced rating tools available:

1. ***BREEAM*** – Building Research Establishment's Environmental Assessment Method is the leading and most widely used environmental assessment method for buildings. It was developed in the UK in 1990 and is the building environmental assessment method with the longest track record. http://www.breeam.org/index.jsp
2. ***LEED*** – The Leadership in Energy and Environmental Design Green Building Rating System, developed by the U.S. Green Building Council (USGBC) in 1998, provides a suite of standards for environmentally sustainable construction. Since its inception in 1998, LEED has grown to encompass more than 14,000 projects in the US and 30 countries covering 99 billion m² of development area. http://www.usgbc.org/leed
3. ***CASBEE*** – Comprehensive Assessment System for Building Environmental Efficiency) was developed in Japan in 2001. There are 4 basic versions of CASBEE which correspond to the individual stages of the building's lifecycle (Pre-design, New Construction, Existing buildings and Renovation). http://www.ibec.or.jp/CASBEE/english/index.htm
4. ***GREEN STAR*** – is a voluntary environmental rating system for buildings in Australia. It was launched in 2003 by the Green Building Council of Australia. The system considers a broad range of sustainable issues while also considering occupant health and productivity, and cost savings. http://www.gbca.org.au/green-star/
5. ***HK-BEAM*** – was developed 1996 in Hong Kong by the BEAM Society. It aims at promoting voluntary initiatives to measure, improve and label the environmental performance of buildings on environmental sustainability. http://www.beamsociety.org.hk/en_index.php

Figure 1 Methodology

2 Criteria	3 BREEAM	4 LEED	5 CASBEE	6 GREEN STAR	7 HK-BEAM
Methodology Summary	Score-based system. Buildings	Score-based system. Buildings	Building is rated based on the "BEE	Score-based system. Buildings	Score-based system. Buildings

	performance is rated based on overall score	performance is rated based on overall score	Factor"	performance is rated based on overall score	performance is rated based on overall score
Weightings	Applied to each issue category	All credits equally weighted	Highly complex system applied at every level	Applied to each issue category	Applied to each issue category
Ratings levels	5 levels	4 levels	5 levels	6 levels	4 levels
Standardization	Yes	Yes	Yes	Yes	Yes
Quantitative criteria	Yes	Yes	Yes	Yes	Yes
Qualitative criteria	Yes	Yes	Yes	Do not meet criteria	Yes
Life-cycle Assessment	Yes	Under development	Yes, but with exceptions	Yes, but with exceptions	Yes
Complexity	Average	Basic	Sophisticate	Basic	Average
Efficiency	Average	High	Very high	Average	Average

Figure 2 Applicability

Criteria		BREEAM	LEED	CASBEE	GREEN STAR	HK-BEAM
Stages of building lifecycle influenced	Pre-Design/Planning/Site Selection	No	No	Yes	No	No
	Design/Procurement	Yes	Yes	Yes	Yes	Yes
	Construction/Post Construction Review	Yes	Yes	No	Yes	No
	Existing Building Management/Operations	Yes	Yes	Yes	Under development	Yes
	Refurbishment	Yes	Yes	Yes	Yes	No
	Demolition	No	No	No	No	No
Technical Contents	Social & Economical Aspects	High	High	Average	Average	Average
	Energy & Resources Consumption	High	High	Average	Average	High
	Environmental Loadings	High	High	High	Average	Average
	Living Quality	High	Average	Average	High	High
	Management & Other Aspects	High	High	Average	High	Average

Figure 3 Data Collecting.

8 Criteria	9 BREEAM	10 LEED	11 CASBEE	12 GREEN STAR	13 HK-BEAM
Data Gatherer	Management team or assessor	Management team or Accredited	Design/Management team	Design team	Management team or Assessor

		Professional			
Data Collection Method	Checklists or Online-spreadsheet	Checklist or Excel spreadsheet	Excel spreadsheet	Excel spreadsheet	Checklists or Online-spreadsheet
Documentation Types	Online and/or hardcopy (drawings, surveys, reports, contracts, etc.)	Online and/or hardcopy (drawings, specifications, reports, etc.)	Online spreadsheet, no hardcopy	Online and/or hardcopy (drawings, surveys, reports, contracts, etc.)	Hardcopy (drawings, surveys, reports, contracts, agreements, etc.)
Stage of project	Design Review and Construction Review	Design Construction and Operation	Preliminary and execution design, completion	Design Review and As Built Review	Design Review and Construction Review
Ease	No	No	No	Yes	Yes, but with exceptions
Measurability	Yes, but with exceptions	Yes, but with exceptions	Yes, but with exceptions	Yes	Yes, but with exceptions
Convenience	Yes, but with exceptions	Yes, but with exceptions	Yes, but with exceptions	Yes	Yes, but with exceptions

Figure 4 Accuracy and Verification

Criteria		BREEAM	LEED	CASBEE	GREEN STAR	HK-BEAM
Accurancy of Data Inputting		High	High	High	Low	Medium
Accuracy of Data Processing		Medium	Medium	High	Medium	Medium
Accuracy of Data Outputting		Medium	Low	High	Medium	Low
Assessor Qualification		Trained and licensed by BRE	Trained and must pass an assessor examination. Must be a first-class architect.	Trained and must pass an assessor examination	Trained and certified by GBCA	Trained and certified by HK-BEAM Society
Verification	Level of Detail of Check	Detailed assessment of documents	Administrative and credit audits	Document review (depends on the selection of tolls)	Detailed assessment of documents	Detailed assessment of documents
	Third Party	Yes	Yes	Yes, but if required	Yes	Yes
	Acknowledged	Yes	Yes	In development	No	In development

Figure 5 User-friendliness

14 Criteria		15 BREEAM	16 LEED	17 CASBEE	18 GREEN STAR	19 HK-BEAM
Ease of use		Yes	Yes	No	Yes, but with exceptions	Yes
Product support	Direct request for assistance	Yes, but with exceptions	Yes, but with exceptions	Yes, but with exceptions	Yes, but with exceptions	Yes
	Record of Enquiries and FAQs	Yes, but with exceptions	Yes	Yes, but with exceptions	Yes, but with exceptions	No
	Availability of training	Yes	Yes	Yes	Yes	Yes, but with exceptions
	Built-in instructions/helps	Yes	Yes	Yes, but with exceptions	Yes	Yes

Figure 6 Development

20 Criteria		21 BREEAM	22 LEED	23 CASBEE	24 GREEN STAR	25 HK-BEAM
System Maturity	Launch Date	1990	1998	2001	2002	1996
System Stability	Testing & Development	Yes	Yes	Yes	Yes	Yes
	System & Revisions	Yes	Yes	Yes, but with exceptions	Yes	Yes
Update	Update period	Annually	2 years	Annually	Annually	As required
	Latest revision	2014 (announcement)	2013	2013	2014	2013
Development Approach	Consensus-based	No	Yes	Yes	No	In development
	Life-Cycle Analysis	Yes	In development	Yes, but with exceptions	Yes, but with exceptions	Yes
	Expert Opinion	Yes	Yes	Yes	Yes	Yes

BREEAM and LEED - with their strong bases, large investments and proven advantages – both scored the high level group. CASBEE, GREEN STAR and HK-BEAM make up the lower group. All of these 3 systems are the upcoming ones that are trying to have more influence across the field. The information, analyses, valuations and comparisons during the process would help architects, developers, managers, etc. to have better insight into sustainable rating tools. They provide a systematic and valuable reference source for various researches which are related to sustainable development.

Furthermore, there is a wide range of research specifically focused on the development and application of appropriate models and strategies for building performance assessment and diagnostics. For instance, three approaches to evaluate building energy performance, including computational-based approach relying on input data from energy audits, performance based approach through analysis of building utility bills, and measurement-based approach with in situ measurement procedures have been summarized[1]. B. Poel, et al [2] provided an overview of the methods and software that can be used for energy performance assessment of existing dwellings, O. Mejri et al [3] presented the application of model identification techniques for energy performance assessment of occupied buildings. It is stated that building typology can be adopted as a tool for estimating the energy performance of residential buildings As studied by E.G. Dascalaki et al[4], building typology can be employed for initial energy advice activities to give building owners a quick overview of building energy performance. An easy-to-use tool for fault detection and diagnosis of building air-conditioning systems has been developed by Y.H. Song, et al [5]. A decision-making tool was used to evaluate the general state of office buildings with respect to deterioration, functional obsolescence, energy consumption and indoor environmental quality[6]. For a particular project, the appropriate performance assessment method and diagnostics tool can be selected by taking into account the client requirements, experience of energy services companies, major retrofit focus, etc.

[1] V. Richalet, F.P. Neirac, F. Tellez, J. Marco, J.J. Bloem, HELP (house energy labeling procedure): methodology and present results, Energy and Buildings 33 (2001) 229–233.

[2] B. Poel, G.V. Cruchten, C.A. Balaras, Energy performance assessment of existing dwellings, Energy and Buildings 39 (2007) 393–403.

[3] O. Mejri, E.P.D. Barrio, N. Ghrab-Morcos, Energy performance assessment of occupied buildings using model identification techniques, Energy and Buildings 43 (2011) 285–299.

[4] E.G. Dascalaki, K.G. Droutsa, C.A. Balaras, S. Kontoyiannidis, Building typologies as a tool for assessing the energy performance of residential buildings – a case study for the Hellenic building stock, Energy and Buildings 43 (2011)
3400–3409.

[5] Y.H. Song, Y. Akashi, J.J. Yee, A development of easy-to-use tool for fault detection and diagnosis in building air-conditioning systems, Energy and Buildings 40 (2008) 71–82.

[6] D. Caccavelli, H. Gugerli, TOBUS – a European diagnosis and decision-making tool for office building upgrading, Energy and Buildings 34 (2002) 113–119.

26 Evaluation of building energy performance

Reliable estimation and quantification of energy benefits are essential in a sustainable building retrofit decision-support system for prioritisation of retrofit measures. The performance of different retrofit measures is commonly evaluated through energy simulation and modelling. There are a variety of whole-of-building energy simulation packages, such as Ansys Fluent, eQUEST, Therm, TRNSYS, MATLAB, SIMULINK, etc., that can be used to simulate the thermodynamic characteristics and energy performance of different retrofit measures. Due to the variety of methods applied, an optimization process can be subdivided into smaller steps and phases in different ways, including a preprocessing phase, an optimization phase and a post processing phase. These three optimization phases and potential tasks at each phase are listed in Fig 7.

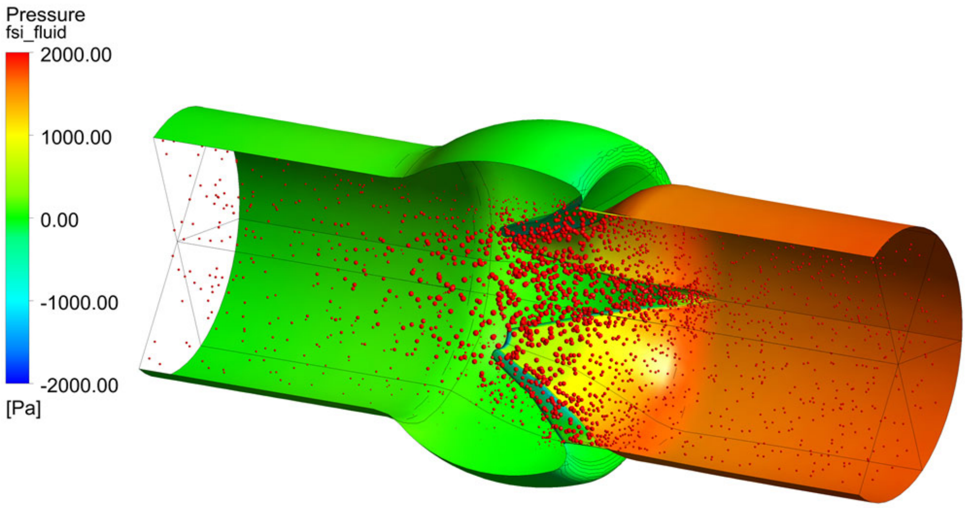
Figure 7 Major phases in simulation-based optimization studies of buildings.

Phase	Major task
Preprocessing	Formulation of the optimization problem: • Computer building model • Setting objective functions and constraints • Selecting and setting independent (design) variables and constraints • Selecting an appropriate optimization algorithm and its settings for the problem in hand • Coupling the optimization algorithm and the building simulation program (optional) Screening out unimportant variables by using sensitivity analysis so as to reduce the search space and increase efficiency of the optimization (optional) Creating a surrogate model (a simplified model of the simulation model) to reduce computational cost of the optimization
Running optimization	Monitoring convergence Controlling termination criteria Detecting errors or simulation failures
Post-processing	Interpreting optimization results (optional) Verification and comparing optimization results of surrogate models and real model for reliability (optional) Performing sensitivity analysis on the results Presenting the results

ANSYS Fluent (CFD) – The Computational Fluid Dynamics (CFD hereinafter for short) allows quantitative assessment of the most relevant variables (temperature, velocity, turbulence intensity, etc.) and detailed view of the same patterns in a virtual environment, convert a test where products and/or facilities in early stages of design. It is in these phases that the information provided by such simulations is crucial, since it is cheaper to make changes, if appropriate, to reach an optimum level of comfort or any critic parameters chosen to evaluate the performance of the tested configuration.

ANSYS Fluent CFD is a tool that provides a complete solution for fluid-dynamics modeling of flow and other related physical phenomena. In turn, this software integrates tools needed to design and optimize new equipment and improve existing equipment and processes. The technology has offered an insight into how a product design will behave in the real world, before building a single prototype. The CFD analysis aimed very accurately simulate the behavior of the wide range of fluids, Newtonian or non-Newtonian, single phase or multiple phases, and subsonic or supersonic. Each applet solution is a highly reliable, having been validated and optimized for simulation in a time optimized. The integration of ANSYS Fluent provides users superior bi-directional connections to all major CAD systems. The platform also allows data and results can be shared with other applications, for example to use a solution of fluid flow for defining a load limit in a subsequent simulation to evaluate the structural mechanics of a domain.

Figure 8 Two-way transient analysis of flow, computed with ANSYS Fluent7.



eQUEST – This energy simulation tool allows users to develop three-dimensional models for simulating a design of a particular building. These simulations incorporate building location, orientation, type of enclosure, the properties of window and HVAC systems, day-lighting and various control strategies, along with the ability to evaluate design options for the combination of energy conservation measures. eQUEST was designed to permit completion of a detailed state of the art design technology is used today in regard to building energy analysis techniques. The complexity of the simulation model, can range from a simple box and one zone, the possibility to import files from AutoCAD DWG, complex schedules, fares, etc. As outputs this software provides: summary of the inputs (schedules, characteristics of building construction, component overview of the peak loads), HVAC system characteristics (features input, the size of the system, execution times, the capacity and the flow of air/oil), reports of construction components user specified time and power consumption of each of the zones of the building, including many variables.

Figure 9 Three-dimensional models for simulating a design of a particular building, by eQUEST.

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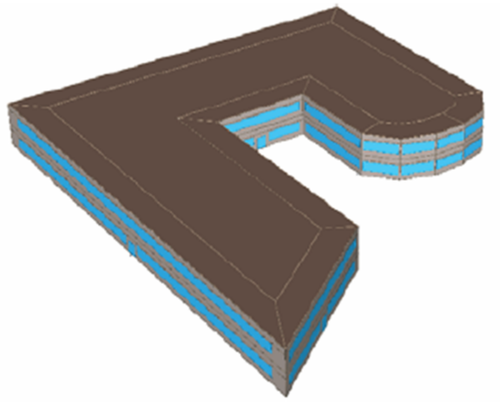
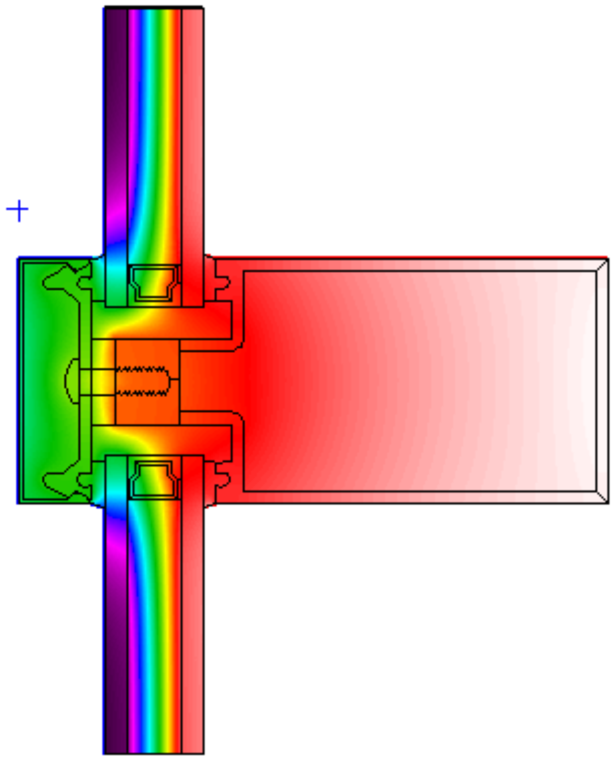
[7] http://www.ansys.com/Products/Simulation+Technology/Fluid+Dynamics/Fluid+Dynamics+Products/ANSYS+Fluent



THERM – is a software tool developed at the Lawrence Berkeley National Laboratory (LBNL) for use by building component manufacturers, engineers, architects, and others interested in the transfer of heat. Using THERM, you can model two-dimensional heat transfer in existing building elements such as windows, walls, foundation, roof and doors, appliances, and other products where thermal bridges are of study. Using THERM allows evaluating the energy efficiency of a product from the existing patterns of local temperature in the area, allowing at the same time relate these to possible problems that could get condensation to appear. THERM is a module of the WINDOW+5, which is also developed by LBLN, which performs a two-dimensional simulation of the conduction heat transfer through the finite element method, and can model this way the complex geometries of the various elements used construction. THERM feature results from the determination of total transmittance elements to calculate the linear heat transfer that occurs in the thermal bridge, through calculate surface temperature and interstitial potential for calculating indoor and outdoor condensations.

Figure 10 Curtainwall with bolt-cross section with IR, by THERM[8]**.**

[8] http://windows.lbl.gov/software/therm/therm.html



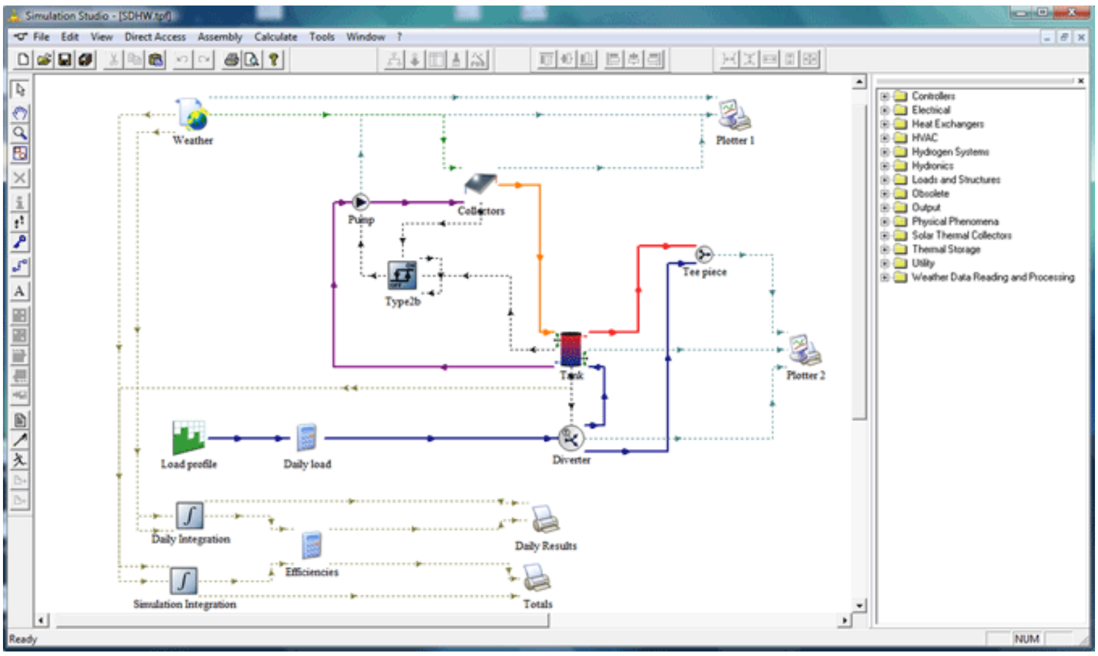
TRNSYS – is a powerful calculation tool that allows transient resolution of any type of system and although it focuses on the evaluation of the thermal and electrical behavior of systems, TRNSYS allows ones to design and optimize energy systems (including Renewable Energy Systems based) and buildings of low power consumption (buildings NZEB - Net Zero Energy Building and ZEB - Zero Energy Building). TRNSYS consists of two parts. The first is an engine (called kernel) that reads and processes the input file, iteratively solves the system and determines the convergence and displays system variables. The kernel also provides utilities (among other things) to determine the thermo-physical properties, invert matrices, perform linear regression, and interpolation of external data files. The second part of TRNSYS is a comprehensive library of components; each component models the performance of the system. The standard library includes approximately 150 models ranging from pumps to multizone buildings, through wind turbines, electrolyzers, meteorological data processing routines, basic economics or HVAC equipment with new emerging technologies. The models are constructed in such a way that users can modify existing components or write your own component, extending the capabilities of the environment. TRNSYS is a component-based program, which adapts to the ever changing needs of researchers and professionals in the community energy simulation. With the release of TRNSYS17 is available plugin for Sketch-Up, which facilitates insertion of the geometric model of building in TRNSYS from its 3D model. With this plug-in is carried out with the description of the building faster and easier than in previous versions of TRNSYS. TRNSYS has a wide range of users worldwide, researchers, energy consultants, and engineers, experts in building simulation, students or architects. For this range of users, the long history of the tool and its inherent flexibility, TRNSYS is used in:

- Simulation of buildings (including modeling for LEED certification);
- Solar thermal processes;
- Process simulation of heat transfer with the ground;

- High temperature solar applications;
- Geothermal heat pumps;
- Several coupled simulation/modeling thermal airflow areas;
- Optimization of energy systems;
- Research and development systems of energy production and distribution;
- Assessment of Emerging Technologies;
- Plant biomass, cogeneration and tri-generation;
- Fuel Cells;
- Wind and Photovoltaic Systems;
- Calibration models of buildings and systems with real operating data

At the policy level TRNSYS is recognized for both applications such as solar systems and buildings. For applications in solar systems TRNSYS is the reference tool for SRCC ratings in USA and European standards appears in solar thermal systems (ENV-12977-2). For applications in buildings TRNSYS complies with ASHRAE 140 and can be used for compliance with ASHRAE 90.1, complies with the European directive on energy efficiency in buildings and is used to verify energy credits in the LEED certification process. Despite the fact that its libraries TRNSYS contains the most common energy systems, the user can easily modify or create new components for technologies not covered by the standard library, because the software is open source and has a method to add new modules based on the Fortran source code. Due to the large number of TRNSYS users worldwide, there are no standard libraries available that simulate the behavior of other components. There is a component library repository and the authors are at the service of the scientific community source code. There are also libraries of components sold TRNSYS distributors from heat pumps and geothermal systems to detailed models of solar collectors, drivers or pools.

Figure 11 TRNSYS simulation interface9.



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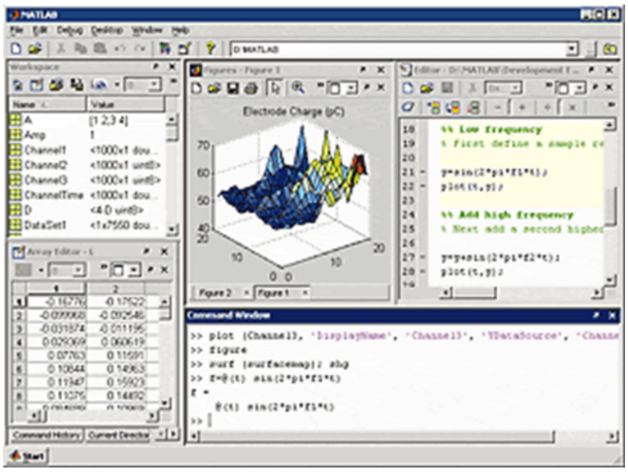
[9] http://www.trnsys.com/

MATLAB – is a technical computing language high-level and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. With MATLAB, you can solve problems faster than traditional languages such as C, C + + and FORTRAN technical computing. MATLAB can be used in a wide range of applications including signal and image processing, communications, control systems design, systems test and measurement, financial modeling and analysis, and computational biology. In addition, MATLAB contains a number of features for documenting and sharing your work. You can integrate your MATLAB code with other languages and applications, and distributed algorithms and applications development using MATLAB.

Key Features:

- High-level language for technical computing;
- Development environment for managing code, files and data;
- Interactive tools for exploration, iterative design and problem solving;
- Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, and numerical integration;
- Two- and three-dimensional graphics functions for visualizing data;
- Tools to create custom graphical user interfaces;
- Functions for integrating MATLAB based applications and external, such languages as C / C + +, Fortran, Java, COM, and Microsoft Excel algorithms.

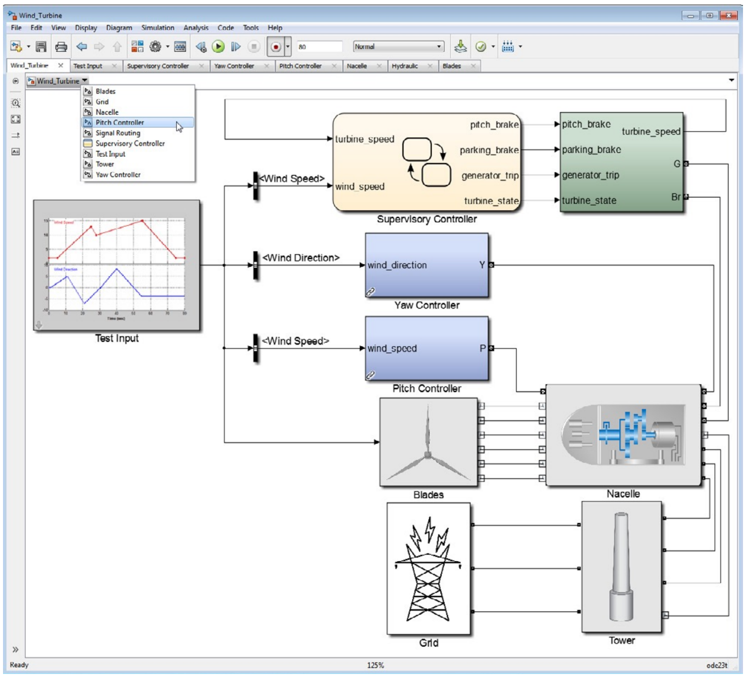
Figure 12 MATLAB interface.



Simulink – is an environment for multi-domain simulation and Model-Based Design for dynamic and embedded systems. Presents an interactive graphical environment and a customizable set of block libraries that let you simulate, implement and test a number of systems with time variables. Simulink is integrated with MATLAB® and provides immediate access to a wide range of tools to develop algorithms, analyze and visualize simulations, create a series of batch processing, customize the modeling environment and define signals, parameters and test data.

Figure 13 Simulink model of a wind turbine[10]**.**

[10] http://www.mathworks.es/products/datasheets/pdf/simulink.pdf



Besides building energy simulation packages, a variety of energy simulation models have been developed and used to estimate energy performance of different retrofit measures. The models range from detailed physical models to grey box models and black box models. A multi-objective mathematical model to provide the decision support in the evaluation of technology choices for building retrofit strategies have been developed[11]. This model explicitly allows for the simultaneous consideration of all available combinations of alternative retrofit actions. A new transient building physics and energy supply systems modeling process for simulating the effect of large sets of building retrofit options have been presented[12]. The strength of this model is in its applicability to real retrofit investment contexts with respect to decision-making. In the context of a particular case study could be stated that a static simulation modeling technique is sufficient as an underlying technique for retrofit analysis. An artificial neural network (ANN) was used in order to predict the energy savings for building equipment retrofits[13]. An evidence-based methodology for calibration of whole building energy models have been presented[14]. This methodology can improve model accuracy through using building verifiable information in the model calibration process. The calibrated models can be used to analyse and estimate the energy savings of different retrofit measures.

Building information modelling (BIM) can also be used to predict the energy performance of retrofit measures by creating models of existing buildings, proposing

[11] E. Asadi, M.G. Silva, C.H. Antunes, L. Dias, Multi-objective optimization for building retrofit strategies: a model and an application, Energy and Buildings 41 (2012) 81–87.
[12] A.M. Rysanek, R. Choudhary, A decoupled whole-building simulation engine for rapid exhaustive search of low-carbon and low-energy building refurbishment options, Building and Environment 50 (2012) 21–33.
[13] M. Yalcintas, Energy-savings predictions for building-equipment retrofits, Energy and Buildings 40 (2008) 2111–2120.
[14] P. Raftery, M. Keane, J. O'Donnell, Calibrating whole building energy models: an evidence-based methodology, Energy and Buildings 43 (2011) 2356–2364.

alternatives, analysing and comparing building performance for these alternatives and modeling improvements[15].

The studies above showed that energy simulation plays an essential role in analysing the performance of retrofit measures. Since different models (and tools) offer different prediction reliabilities with different uncertainties, the model (and tool) selection and its parameter identification are essential to ensure reliable estimates. It is worthwhile to note that simulation packages and energy models are generally developed based on certain assumptions. It is important for users to recognise the simulation uncertainties generated by such assumptions.

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[15] L. Tobias, G. Vavaroutsos, et al., Retrofitting Office Buildings to be Green and Energy-Efficient: Optimizing Building Performance, Tenant Satisfaction, and Financial Return, Urban Land Institute (ULI), Washington, DC, 2009.