INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN 2278 – 0211 (Online)

A Review of Building Simulation Articles

Fadeyi Ayomipo Akintunde
Department of Architecture, College of Environmental Sciences, Bells University of Technology, Ota
Abass Dare Abideen
Department of Architecture, College of Environmental Sciences, Bells University of Technology, Ota

Abstract*:*
In simple terms, building simulation attempts at understanding how a given building operates according to certain criteria (site location, massing, orientation, envelope – fenestrations: size, location, glazing etc.) and enable comparisons of different design alternatives right from its conceptual design stages. Various energy simulation tools are employed to predict the energy performance of a building, assess the energy use and quantify the savings attributable to the proposed design. This became crucial because the building industry is under intense pressure to provide value for money, making sustainable design more important now than ever. Riding on the wings of technology that brought about the introduction of Computer Aided Design (CAD) in the industry from it primitive two-dimensional (2D) base drawing system to the more advanced three-dimensional (3D) parametric modeling as it is found in Building Information Modeling (BIM) technology today, and most recently, a further manipulation of the "Information" inherent in the digital models to perform analysis of proposed buildings in it intended environment under varying conditions. Building simulation make sustainable design practices easier by enabling architects and engineers to more accurately visualize and analyze building performance earlier in the design process. Amidst the vast application of various energy analysis tools in the industry today, this paper presents a review of relevant building energy simulation articles mainly from an architectural perspective, by highlighting the roles they have played in the industry and an overview of what they portend for sustainable design in the nearest future.

Keywords*: Building Information Modeling (BIM), Computer Aided Design (CAD), energy analysis; simulation tools, sustainable design*

1. Introduction

Building simulation involves the use of computer generated 3D models to mimic the behavior of a real or proposed building design system (http://www.simul8.com/), such as day-lighting, air-flow (ventilation), acoustics or thermal comfort. These intelligent 3D models brought about by BIM technology creates, modifies, shares, and coordinates information throughout the design process (http://www.autodesk.co.uk/), thereby providing a platform for an alternative to real life experiment. Simulation is time based, matches reality and no doubt a tool for effective testing. As an alternative to real life experiment, the procedure is cost effectiveness, time efficient and can be repeated as much as possible. In some complex scenarios, simulation seems the only solution to the design challenge at hand, while also getting the designer thinking about other aspects of the process (http://www.simul8.com/).

Simulation results are visual and animated. It clearly describes the proposal to others. It is more convincing, and it has become so effective at communicating ideas that the Architecture, Engineering and Construction (AEC) industry now uses it as a tool to drive sustainable design. No doubt, simulation has come to stay in the industry.

It has been argued that using simulation in design is both enabling and disruptive. On the one hand, simulation provides a great set of technical toolkits to optimize and create higher performance designs; while on the other hand, it entails a new cognitive model at the intersection of design inquiry and scientific method of reasoning (https://uk.sagepub.com). Considering the fact that the introduction of simulation to architecture holds a brief history; only in recent years have simulation tools and techniques started to transform the approach to design of the built environment. In fact, research in the context of built environment is still in its infancy, and the broader impact and potentials of leveraging such method is yet to be fully examined in future years (http://scs.org/). That is the reason for this review, to put the evolution of building simulation in perspective.

2. History of Building Simulation

Building simulation as a discipline can be traced back to the 1960's when the United State (US) government was involved in projects to evaluate the thermal environment in fallout shelters (Kusuda, 1999).Though Haberl et al. (2004) noted that as early as 1925, Nessi and Nisolle had used Response Factor Methods (RFM's) to calculate transient heat flow.Just about then, the merger of *American Society of Heating and Air-Conditioning Engineers* (ASHAE) and the *American Society of Refrigerating Engineers* (ASRE) formed the *American Society of Heating, Refrigeration, and Air-Conditioning Engineers* (ASHRAE).That has remained an important nexus for the development and dissemination of building energy modeling techniques (www.bembook.ibpsa.us/index.php).

2.1. Pre-Computer Days

During the '50s and '60s, many engineering calculations were still done by slide rules and desktopelectromechanical calculators such as Monroe, Frieden and Tiger (Kusuda, 1999).Such were attempts by Prof. James Threlkeld, a refrigeration expert, in the mid '50s as reported by Kusuda (1999). Prof. James Threlkeldtried to develop a mathematical formula to predict the pull-down performance of a refrigerated warehouse during a HVAC&R research, but found it difficult to include the refrigeration system performance into the equation. The use of a graphical method called the *Schmidt Plot* was resorted to, to couple the transient heat transfer through the multi-layered structure to the performance curve of the refrigeration system. The graphical method was able to simulate the heat balance among the transient heat conduction gain through the envelope of the test chamber, air cooling coil capacity, and refrigeration compressor cooling capacity to predict the temperature pull-down. The predicted value for the test chamber very closely agreed with the pull-down temperature data that was collected. This marks the first success story at building energy simulation.

2.2. Beginning of Computer Use

In the late 1960s, as accounted by Wright (2003), the National Bureau of Standards (NBS) acquired some of the most advanced computers in the US. Bradley Peavy, an NBS scientist, took advantage of the computing power at NBS and developed techniques to map heat conduction in underground fallout shelters. His 1968 paper titled "*Analytical Studies of Probe Conduction Errors in Ground Temperature Measurement*" details his research.Building upon Peavy's work, Tamami Kusuda developed a computer program to predict thermal performance (Wright, 2003). The program, which relied on the *Response Factor Method* (RFM), was very basic and could only model a single room. However, this was a major first step towards *Whole Building Energy Modelling*according to the *National Institute of Standards and Technology* (NIST).Frank Powell and Douglas Burch validated the accuracy of Kusuda's model (NIST), and it laid the groundwork for future Building Energy Modelling (BEM) programs.

2.3. Present: ASHRAE, LEED, and BIM

No doubt, the past decade has witness a remarkable growth in the BEM, primarily driven by stringent building standards and growth in voluntary certification programs.*American Society of Heating, Refrigeration, and Air-Conditioning Engineers* (ASHRAE), *United States Green Building Council* (USGBC) and *Leadership in Energy and Environmental Design* (LEED) recognized the necessity of program certification for specific modelling tasks, as early as year 2000 (http://www.bembook.ibpsa.us/index.php).Perhaps, the most significant change in the way data for BEM is processed and analysed occurred in the past decade when major software developers acquired companies with energy modelling capabilities, giving rise to BIM tools and the development of simulation engines;*DOE-2*, *Energy Plus*, *Green Building Studio* (GBS) that directly import files from BIM software in a gbXML format (Malin, 2008, Shady A. et al. 2009).

2.4. Present: Building Simulation Status

In spite of the tremendous improvement that has happened to the technology and techniques of building simulation program, it is yet to be recognized as design support tools to the same extent as CAD tools. For this reason, architects and designers are still finding it difficult to use even basic simulation tools (Punjabi et al. (2005) as cited in Shady A. et al. (2009). Evidence for poor uptake of the technology by the industry can be found in the literature (Andre at al. 1994, Bauer et al. 1998, De Wilde et al. 1998, Robinson 1995, Hien et al 2000 as cited in Morbitzer C. et al., 2001) and in the fact that, for example, the International Conference on Construction Information Technology 2000 (Reykjavik, Iceland) contained only one paper on Dynamic Building Simulation but a number of papers on Virtual Reality in Construction. This conclusion was also confirmed by visits to a number of typical building design practices (Morbitzer C. et al., 2001).

3. Why Perform Building Simulation?

Buildings can be said to be a primary contributor to global warming and ozone depletion since approximately one-third of our primary energy supply is consumed in buildings (Hong T. et al., 2000). Consequently, achieving better energy efficiency in buildings has become one of the world's major challenges.

It is estimated that substantial energy saving can be achieved from a conventionally designed building through careful planning for energy efficiency. To achieve this today, the technique available to architects, engineers and building managers concerned with energy conservation is building simulation (Shaw, 1995) and (Clark et al, 1988).Building Simulation Programs

(BSP) now runs on PCs, allowing architects and engineers to test out new designs before proceeding to construction and installation. Furthermore, Hong T. et al. (2000) stated that through parametric analyses, professionals can extend their design concepts to incorporate new technologies and innovation thus creating opportunities for increased energy saving. And worldwide, numerous researches are being funded with focus on building energy efficiency, and the results are been used internationally to develop relevant standards and guidelines. Hence, it can be seen that building simulation is one of the key technologies that contribute to the construction of future buildings which are more energy efficient, health responsive and environmental-friendly.

4. How Is Simulation Applied?

The use of CAD to produce technical documents and drawings is already popular with building designers, but simulation which often requires the use of engineering tools to calculate envelope heat gains and space heat loads, predict the energy performance of the building, and provide diagnostics to enable automatic control of system and plant operation is still being grappled with by professionals in the industry. While the former assist to improve the productivity of building designers, it has little or no impact on efficiency of the building performance. Hong T. et al. (2000) ascertained that only simulation holds the key to improving building energy efficiency. For the intense pressure on building designers to provide value for money, sustainable design and construction in the industry today, the use of computer simulation is now considered commonplace. According to Hong T. et al. (2000), there are several popular applications for this. They include;

- Building heating/cooling load calculation
- Energy performance analysis for design and retrofitting
- Building Energy Management and Control System (EMCS) design
- Complying with building regulations, codes and standards
- Cost analysis
- Studying passive energy saving options
- Computational Fluid Dynamics (CFD)

5. What are the Available Building Simulation Programs?

BSPs can be grouped into two categories, namely, Design Tools (DTs) and Detailed Simulation Programs (DSPs) (Hong T. et al., 2000).DTs are purpose-specific and are often used at the early design phase because they require less and simpler input data. They are developed for in-house use, and can mostly be found in public domain. On the other hand, DSPs often incorporate computational techniques for building load and energy calculations. They perform computations on an hourly (sometime even by the minutes) and zone-by-zone basis to account for the dynamic interactions among all the thermal-based elements associated with comfort and energy consumption e.g. building envelop, lighting, HVAC etc. Thus, optimal design and operation of a building and its facilities can be achieved. Some of the most popular DSPs in use include;

5.1. DOE-2

It is building energy analysis program that can predict the energy use and cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills. The “plain” DOE-2 program is a “Command Prompt” program which requires substantial experience to learn to use effectively while offering researchers and experts significant flexibility; eQUEST is a complete interactive Windows implementation of the DOE-2 program with added wizards and graphic displays to aid in the use of DOE-2 (http://doe2.com/). The development of DOE-2 was sponsored by the US Department of Energy (DOE). It was developed by the Simulation Research Group at Lawrence Berkeley Laboratory (LBL), and was first released in 1979. Since then, the computer code has evolved into a PC-based BSP (Hong T. et al., 2000).

5.2. Energy Plus

Energy Plus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting, and plug and process loads—and water use in buildings. It is funded by the U.S. Department of Energy (DOE) Building Technologies Office (BTO), and managed by the National Renewable Energy Laboratory (NREL). Energy Plus is developed in collaboration with NREL, various DOE National Laboratories, academic institutions, and private firms. Some of the notable features and capabilities of Energy Plus include:

- Integrated, simultaneous solution of thermal zone conditions and HVAC system response that does not assume that the HVAC system can meet zone loads and can simulate unconditioned and under-conditioned spaces.
- Heat balance-based solution of radiant and convective effects that produce surface temperatures, thermal comfort, and condensation calculations.
- Sub-hourly, user-definable time steps for interaction between thermal zones and the environment, with automatically varied time steps for interactions between thermal zones and HVAC systems. These allow Energy Plus to model systems with fast dynamics while also trading off simulation speed for precision.

- Combined heat and mass transfer model that accounts for air movement between zones.
- Advanced fenestration models including controllable window blinds, electro chromic glazings, and layer-by-layer heat balances that calculate solar energy absorbed by window panes.
- Illuminance and glare calculations for reporting visual comfort and driving lighting controls.
- Component-based HVAC that supports both standard and novel system configurations.
- A large number of built-in HVAC and lighting control strategies and an extensible runtime scripting system for user-defined control.
- Functional Mockup Interface import and export for co-simulation with other engines.
- Standard summary and detailed output reports as well as user definable reports with selectable time-resolution from annual to sub-hourly, all with energy source multipliers. (http://apps1.eere.energy.gov/buildings/energyplus/)

5.3. Green Building Studio (GBS)

Green Building Studio is a flexible cloud-based service that allows architects and designers to run building performance simulations to optimize energy efficiency and work toward carbon neutrality earlier in the design process. It features includes;

- Whole-building energy analysis
- Detailed weather data
- Energy Star and LEED support
- Carbon emissions reporting
- Day lighting
- Water usage and costs
- Natural ventilation potential

(http://www.autodesk.com/products/green-building-studio/overview)

Others are;

- Conjunction of Multizone Infiltration Specialist (COMIS)
- Environmental System Performance (ESP)
- Computer Models for the Building Industry in Europe (COMBINE)
- Transient Systems Simulation (TRNSYS)

6. How to Choose a Simulation Program

With the abundance of simulation programs in the industry today, it is good to know that for any given problem there is usually more than one BSP that can meet the requirement. That is not to say that a single BSP can perform all kinds of building simulation. According toHong T. et al. (2000), the choice of an appropriate program can be made after carefully assessing the requirements of the user against the capabilities of the BSP.

6.1. The Requirements of the User

On the part of the user, three factors to be considered are;

- Need/Purpose – understanding the nature of the problem that is expected to be solved with the use of the BSP.
- Budget – cost of software, cost of specified computer specification to run such BSP, user's training,maintenance etc
- Availability of facility – BSP that can run on available computer hardware. Thankfully, today most (if not all) BSPs can run on PCs. Availability of input data; weather data, utility rates, energy consumption cost etc.

6.2. The Capabilities of the BSP

Prior to the commercial release of a BSP it would have been tested and validated(Shady A. et al. 2009, Hobbs D. et al. 2003, Augenbroe G., 2001). It performance depends on how well domain knowledge, software engineering, software quality assurance (Sommerville I. (1995) and Manns T. et al. (1996) as cited in Hong T. et al.(2000), and human computer interface (HCI) technology are applied during the development of the BSP (Hong T. et al. 2000, Shady A. et al. 2009).

Based on these, the capability of a BSP can be evaluated on the follow;

- *Computational capability* – as described by attributes such as: (i) core algorithm (ii) application scope (iii) computing speed and accuracy and (iv) user extensibility.
- *Usability* – this can be evaluated by the following stages of its use: (i) learning to use (ii) preparing input data (iii) running the program and (iv) interpreting the results.
- *Data exchange capability* – BSPs should have the capability to import data from and export data to external databases in a universally accepted file format such as; ASCII, DXF, IGES, STEP of gbXML.
- *Database support* – data needed by DSP on building materials and structures, HVAC components, and hourly weather data are usually standardized and stored in selected databases. BSPs should have the capability for such database management.

7. How to Perform Building Simulation

The process for computer simulation of building performance is as illustrated in Figure 1 by Hong T. et al. (2000). It is based on the iterative process of understanding and representing the real world issue.

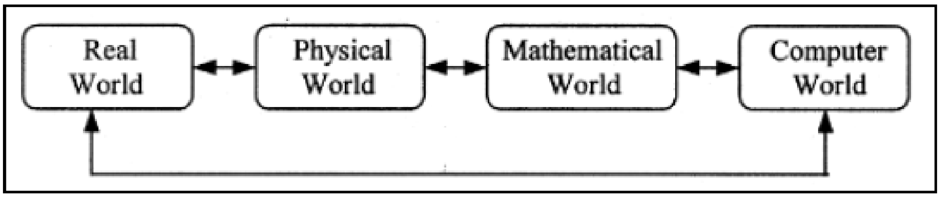

Figure 1: Iterative Process of Computer Modeling

The models are developed by reducing real world physical entities and phenomena to an idealized form on some desired level of abstraction (Computer World). From this abstraction, a mathematical model is constructed by applying physical conservation laws (Augenbroe G., 2001). Due to the complexity of the real world issues, some assumptions, simplifications, and approximations are introduced in the modeling processes. Hence, users can expect solutions with bounded rationality (Simon H. A. (1976) as cited in Hong T. et al. (2000), that is, solutions meeting the degree of accuracy of the user's requirement.Augenbroe G.(2001) assert that effective application of building simulation needs skilled users, suitable BSPs and quality assurance techniques.For these reasons, the road towards a *generic Building Energy Model* in the industry is a long and windy one (Eastman, (1999) as cited in Augenbroe G., (2001). For this reason, Hong T. et al. (2000) reiterates that performing building simulation involves understanding the nature of the issues to be solved, choosing a suitable simulation program, using the simulation program and interpreting the simulation result and making decisions. Hence, the most effective users are those who master the basic concepts and fundamental knowledge of building performance and HVAC systems.Quality assurance should be applied in the following steps in the use of a BSP;

- Mastering how to use a program
- Representing the building
- Preparing the input data
- Running and controlling the simulation
- Interpreting the result and making decisions

8. What Is The Road Ahead?

8.1. Knowledge-based systems

As at today, most BSP cannot provide suggestions to improve design. They only provide results corresponding to what the user inputs. BSP will require domain knowledge support in order to solve such open problems. There is a trend to incorporate BSPs with *Knowledge-Based Systems* (KBS) or *Decision Support System*(DSS) (Shady A. et al. (2009).

8.2. BSPs for early design stages

Decisions taken at the early design stages have a significant impact on the energy performance of a building; building form, orientation, fenestration and construction materials are decided by the architect at the early design stages. The current generation of simulation tools plays no significant role in this stage (Zhai and McNeill, 2014, Augenbroe G., 2001). Other allied professionals are often brought on board after this stage. Hence, it is essential to have BSPs that can assess the energy performance of a building during the sketch design stage.

8.3. Information Monitoring and Diagnostic System (IMDS)

The information monitoring and diagnostic system (IMDS) is a multi-level on-line building diagnostic system, which includes high accuracy sensors, minute-level measuring and monitoring, gigabyte data archival/retrieval, data analysis and 3D visualization, fault detection and diagnosis, intranet and internet capacity and other components, that can be used to provide continuous improvements in O&M so as to reduce building energy use and operating costs.

8.4. Integrated Building Design System (IBDS)

Building design being a multidisciplinary activity involves several professionals; architect and structural, mechanical and electrical engineers. Different BSPs are required at different design stages by different professionals for different purpose of simulation. An IBDS that integrates different BSPs and enables them to exchange data through a standardized building database will be highly desirable for total building design.

8.5. Virtual reality (VR)

Virtual reality is a human computer interface in which the computer creates a 3D sensory immersing environment that interactively responds to and is controlled by the behaviour of the user usually wearing a special glove or helmet (Pimentel K. et al. (1995) as cited inHong T. et al., (2000). VR technology will help building professionals design, construct, operate and manage a building. It will also enable them to move around to experience the building. Architecture, perhaps more than any other field, is poised to reap the benefits of virtual reality.

9. Conclusion

No doubt, building simulation has come a long way and the last decades witnessed the proliferation of simulation software for a broadening range of building performance assessments. Although there remain some weaknesses and gaps in tool functionality, database support and availability of facilities, yet the more immediate challenge is a better integration of simulation in all phase of the building process, in the face of the plethora of BSP available today and it increasing level of quality assurance, to effectively shape the future of the industry considering the turn of events, where sustainable design and construction, energy efficiency, value for money is the order of the day and everyone is going “green”. And as the war of “designer friendly” versus “design-integrated tools” – Graphics User Interface (GUI) vis-a-vis usability and information/data management – is being won in the research community, which would see simulation tasks move progressively toward non-specialist, it is hoped that it usage amongst architects would become commonplace and more allied professionals would utilize the potential inherent in building simulation tools to unlock the potentials it portend to offer.

10. References

i. Kusuda, T. (1999). Early History and Future Prospects of Buildings System Simulation. IBPSA. Japan.
ii. Augenbroe, G. (2001). Building Simulation Trends Going Into the New Millennium. IBPSARio de Janeiro, Brazil.
iii. Morbitzer, C., Strachan, P., Webster, J., Spires, B., Cafferty, D. (2001). Integration of Building Simulation into the Design Process of an Architecture Practice. IBPSA Rio de Janeiro, Brazil.
iv. Shady, A., Beltrán, L., André De Herde, Hensen, J. (2009). “Architect Friendly”: A Comparison of Ten Different Building Performance Simulation Tools. IBPSA Glasgow, Scotland.
v. Hobbs, D., Morbitzer, C., Spires, B., Strachan, P., Webster, J. (2003). Experience of Using Building Simulation within the Design Process of an Architectural Practice. Conference Proceedings; 8th International IBPSA Conference; Eindhoven, Netherlands.
vi. Haberl, J., & Cho, S. (2004). *Literature review of uncertainty of analysis methods*. Manuscript Retrieved from http://repository.tamu.edu/handle/1969.1/2072
vii. Wright, R. N. (2003). *Nbs/nist 1975-2000* [NIST BSS 179, Environmental Systems, pp.13-15]. Retrieved from http://www2.bfrl.nist.gov/info/bfrl_history/
viii. Hong, T., Chou S. K., Bong T. Y. (2000). Building Simulation: An Overview of Development and Information Sources. Journal Article; Building and Environment www.elsevier.com/locate/buildenv
ix. National Institute of Standards and Technology, (n.d.).*Computer program for heating and cooling loads in buildings*.http://nvl.nist.gov/pub/nistpubs/sp958-lide/266-269.pdf
x. Kusuda, T. (1970). *Use of computers for environmental engineering related to buildings*. Proceedings of a Symposiumheld at NBS, Gaithersburg, Maryland.
xi. Malin, N. (2008) *BIM companies acquiring energy modeling capabilities*. GreenSource, Retrieved from http://greensource.construction.com/news/080403BIMModeling.asp
xii. Shaw, M. (1995) Computer Modelling as a Design Tool for Predicting Building Performance. Blue Pages, Building Serv Eng Res Technol 1995;16(4), 1996;17(2).
xiii. . In: Clark, J.A., Irving, A.D. (1988) Energy and Buildings; Special issue on building energy simulation.
xiv. The Pittsburgh Papers (2003). Understanding the Energy Modelling Process: Simulation Literacy 101; Marc Rosenbaum's Writings. http://www.buildinggreen.com/features/
xv. Simulation Explained; http://blog.simul8.com/category/simulation-explained/
xvi. BIM: Building Information Modelling; http://www.autodesk.co.uk/solutions/building-information-modeling/overview
xvii. The Society for Modelling & Simulation International (SCS);SIMULATION SI: Simulation for Architecture and Urban Design; http://scs.org/
xviii. History of Building Energy Modelling; http://www.bembook.ibpsa.us/index.php
xix. The home of DOE-2 based Building Energy Use and Cost Analysis Software; http://doe2.com/
xx. EnergyPlus Energy Simulation Software; http://apps1.eere.energy.gov/buildings/energyplus/
xxi. Green Building Studio; http://www.autodesk.com/products/green-building-studio/overview
xxii. https://uk.sagepub.com/sites/default/files/sim-cfp-architecture.pdf