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# State-of-the-art on buildings performance energy simulations tools for architects to deliver low impact building (LIB) in the UK

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**Abstract**

With an enhanced understanding of sustainability requirements, the usage of design and decision support tools are expected to increase, by which there are several qualitative and quantitative assessment tools, but a dearth of research in decision support mechanisms to help architects achieve low impact design and delivery in the UK. Aiming to give an overview of the present state-of- the- art on Building Performance Energy Simulation (BPES) tools, review of extant literature were carried out along with Questionnaires, emailed to randomly selected architectural practices from the Royal Institute of British Architects (RIBA) directory of architects. The literature review reveals that few tools support the early architectural design process; input quality affects accuracy, while output needs careful expert interpretation. From the questionnaire survey results, small numbers of architects who use existing Building Performance Energy Simulation (BPES) tools, do so at the later stage of the design process. The tools that are used are even those recognised and advertised for the early design stages by the software manufacturers. These are used at the later stage by most architects because they are less complex.

***Keywords:*** Architects, Building Performance Energy Simulation, Design Process, Decision support tools, Low Impact Buildings



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## 1. Introduction

Energy efficiency and thermal comfort are of concern in building design. Since, one third of national total annual energy consumption is consumed in buildings, it is estimated that substantial energy savings can be achieved through careful planning of energy efficiency (Hong et al., 2000; Hetherington et al., 2010). According to the World Business Council for Sustainable Development (WBCSD), with immediate action, the energy use in buildings can be reduced by up to eighty per cent by the year 2050. Compared to any other sector, buildings use more energy than and are major contributors to climate change. In numerous countries, building regulations and environmental guidance ensure that building designer considers building energy performance improvement measures.

For decision making, Building Performance Simulation (BPS) tools, with the aid of computer-based models, cover performance aspects such as energy consumption and thermal comfort in buildings. Crawley (2003) describes Building Performance Energy Simulation (BPES) tools as powerful tools, which emulates the dynamic interaction of heat, light, mass (air and moisture) and sounds within the building. They are to predict the energy and environmental performance exposure to climate, occupants, conditioning systems, and noise sources. However, Hopfe (2009) emphasised that: although, there are large number of BPES tools, most use the same modelling principles and are used in similar manner.

The final goal of this paper is to provide the state- of-the- art on the use of Building Performance Energy Simulation (BPES) tools by the UK architects. Literature review was carried out to provide the basis for an up-to date appraisal. Questionnaires were also emailed to randomly selected architectural practices from the Royal Institute of British architects (RIBA) directory, to evaluate BPES tools at various stage(s) of the design process.

The paper is organised into six sections. The first is this introductory section, which introduces the overview of the paper. The second section is on the ambiguity of tools at the early stage of the design process. The third section is on the background study of Building Performance Simulation (BPS) tools and positioning the trend in their use within the design process and in the building industry profession. Section four discusses the methods and results from the questionnaire survey, on the state - of- the- art on the use of BPES tools by UK architects. Section five provides the discussion and implication of the study, especially to software developers to develop BPS tools, fit for the various stages of the architects' design - decision making to achieve low impact buildings in the United Kingdom (UK). Section six concludes the paper.

## 2. Ambiguity of tools at the early stage of the design process

A wide variety of drawing packages are available for architectural and structural design, with different computer tools currently in use to support the design of new products, including the design of buildings (Aliakseyeu et al., 2006). Progress has been made in terms of design quality and efficiency since the introduction of computer- based drafting and design tools and computer- based simulation tools. The first application, which often uses personal computers to produce technical documents and drawings is popular with building designers and helps to improve their productivity but has minimal influence on decision making for efficient building performance.

The latter application entails the use of simulation tools to calculate envelope heat gains, space heat loads and prediction of energy performance of the building by which, the geometric precision and the large number of required detailed selections required of these simulation tools can only be possible at the later stage of the design process. The required level- of- detail, although necessary for the design at the later stage is often largely irrelevant at the early design stage and tends to distract from the design activity itself. Hong et al. (2000) believe, it is only the computer-aided simulation tools that hold the key to improving building energy efficiency. Lawson (2010) emphasised how the use of such precise programs in early design stage tends to limit creativity and encourage poor design. Moreover, design professionals work in different ways (through sketches, physical models, 2D and 3D computer representations, and analytically) and, thus, have different requirements for representing and communicating design developments (Technology Strategy Board, 2009), which, in most cases, is by drafting, sketching or drawing tools.

Subsequently, use of advanced computer programmes, such as simulation tools, typically enter at the later stage of the design process by architects to aid decision making, has shifted their focus more to the detailed specification stage instead of the early design stage of the design process (Aliakseyeu et al*.,* 2006) where many global and crucial decisions about the design are made.

Mora et al*.* (2006) laid emphasis on how computer support for conceptual design of building structures is still ineffective, mainly because existing structural engineering applications fail to recognise that structural and architectural design are highly interdependent processes. Hopfe (2009) further emphasised how the uptake of BPS in current building design projects is limited, stating, although there is a large number of building simulation tools available, the actual application of these tools is mostly restricted to code compliance checking or thermal load calculations for sizing of heating, ventilation and air-conditions systems in detailed design.

Investigation into current design and decision tools from Technical Strategy Board (TSB) (2009) also made the observation on how design support at the conceptual stage is particularly poor. Designers cannot easily predict the impact of alternative design decisions on building performance and cost – whether capital cost, whole life financial cost or carbon cost at the early stage of the design process (Technology Strategy Board, 2009). Dunsdon et al*.* (2006) argue that the most cost effective carbon reduction measures and decisions are those introduced at the early design stage. Failure to embed low carbon considerations from this stage is likely to result in a building with higher carbon emissions. Better-informed design from the earliest conceptual stage will improve the design of individual buildings.

## 3. Decision support tools

Decision Support Tools (DSTs) can be defined very broadly as '*any tool used as part of a formal or informal decision process*' (Kapelan et al*.*, 2005) or any tool that '*informs the decision-making process by helping actors understand the consequences of different choices*' (Canada Mortgage and Housing Corporation, 2004). While there is no shortage of DSTs created to aid the building professions in meeting new green building requirements, especially at the international level, Keysar and Pearce (2007) state that, there is a knowledge deficit regarding what tools are available and potential benefits associated with their use. For instance, a range of decision support tools are available that are proficient in performing predictive energy assessment, however, "the relatively low level of adoption of these tools by architects suggests, there are some significant barriers to their successful application to the building procurement and design process, especially at the critical early design stages" (Dunsdon et al., 2006, p. 2).

Adeyeye et al. (2007) emphasised how emissions from the construction industry can be minimised from onset. This can especially be achieved through the role of architects; better building designs would reduce energy consumption by 50-75 per cent below the 2000 levels. The architects also have the major responsibility to get the message across in the participatory decision making processes (Chen et al., 2008). Hence, the need for tools that caters to their '*special needs'* of architects.

In the traditional design process, however, it is the energy engineer who uses simulation tools for equipment sizing and code compliance, only after the architect has completed the architectural design (Ellis et al., 2008). Part of the problem is that the existing simulation tools are not fit for design decision making process of architects. Torcellini et al. (2011) made it known that in their experience with real buildings, low-energy design is not intuitive, and simulation should be an integral part of the design process. However, this has not been possible because the development of energy models which describe the building design is time-consuming and requires skilled specialists. Tools should, be used in an integrated design process to complement the designer's own knowledge, by quickly confirming whether proposed changes to a design are likely to make the performance of the design better or worse, and by indicating the relative effects on performance of different design features.

Tools are required to help designers predict how buildings will perform in use, and to support the construction and operation of buildings. It should provide different degrees of confidence, depending on the quality and amount of the input data, the complexity of the calculations and the skill of the user. Thus, when using tools to support the design of a low impact building design, a staged approach should be adopted with complexity of simulation increasing in proportion to the complexity of the design. From the RIBA Climate Change Toolkit 05, it has been made known that all design tools, from simple calculation procedures to complex simulation models, are means of estimating the approximate performance of a given design.

## 3.1. Building performance energy simulation tools and architects trend in their use

Since the inception of the building simulation discipline, it has been constantly evolving as a vibrant discipline that produced a variety of Building Performance Simulation (BPS) tools that are scientifically and internationally validated (Attia, 2010). Foundation work for building simulation was pioneered in the 1960s and 1970s focusing on building thermal performance, addressing load calculation and energy analysis (Clarke, 1985; Kusuda, 1999; Attia, 2010).

The beginning of the 1990s manifested a shift from an energy consumption focus to many other building performance characteristics (Augenbroe, 1992; Attia, 2010). This was supported by Hensen and Radosevic

(2004), who state that the building simulation discipline reached a certain level of maturation to offer a range of tools for building performance evaluation in the 1990s. By the end of the 90s, a range of simulation applications spanned out from the research community to professional practice, allowing a diverse tool landscape for variety of users (Papamichael and LaPorta, 1996; Tianzhen and Jinqian, 1997; Attia et al., 2011). "The maturation of building simulation had a major influence on the building design profession and resulted into four major changes" defined in Attia (2009, p. 5) as:

- Diversifying tools users and addressing more the whole design team;
- Modifying the tools to suite early and late design phases;
- Increasing the number of tools and developing a large range of function complete tools; and
- Localising the tools capabilities.

In this paper, some Building Performance Energy Simulations (BPES) tools are categorised and analysed in Table 1 based on their specific functions, such as energy, renewable and code standard applicability. Table 2 categorised the tools, based on their functionalities/ purpose, file formats, target users and the design stages that the software developers categorised them for use.

**Table 1.** . Functions of some BPES tools

| Tools | Energy Simulation | Renewable Energy | Code Standards | All types of buildings |
|---|---|---|---|---|
| Autodesk Green Building Studio | * | | | * |
| Building Design Advisor | * | | | * |
| Design Advisor | * | | | * |
| DOE-2 | * | * | | * |
| Ecotect | * | * | * | * |
| e-Quest | * | | | * |
| Energy 10 | * | * | | * |
| Energy Plus | * | * | | * |
| ESP- r | * | * | | |
| IES<VE> | * | | | * |

And Table 3 analysed the tools based on their contrasting capabilities in the form of energy simulation characteristics, relationship to CAD, ventilation function, weather data, results and validation

**Table 2.** Building Performance Energy Simulation Tools

| **Tools** | **Functionalities/ Primary Use/Purpose** | **Computer Platform and Programming Language** | **Design Stages it is used** | **Specified Audience and Users** | **Originator** | **Reference/ Source** |
|---|---|---|---|---|---|---|
| Autodesk Green Building Studio | Links architectural building information models (BIM) and certain 3-D CAD building designs with energy, water, and carbon analysis | • Autodesk Revit Architecture (Windows); Autodesk AutoCAD Architecture; Graphisoft Archi CAD<br>• **Programming Language** C#, C++, Visual Basic, XML, XSLT | Early Design Stage | **Architects**, Designers and Construction Managers | Autodesk | http://usa.autodesk.com/green-building-studio/ |
| Building Design Advisor | Supports the integration of multiple building models and databases used by analysis and visualization tools | • PC-compatible Windows<br>• **Programming Language: C++** | Whole Design Project | **Architects** and Engineers mainly in the US | Lawrence Berkeley National Laboratory | http://gaia.lbl.gov/BDA/ and http://apps1.eere.energy.gov/buildings/tools_directory/doe_sponsored.cfm |
| Design Advisor | Energy simulators that model energy, comfort, and day lighting performance. It also gives estimates of the long-term cost of utilities | Web-based<br>• **Programming Language** Java, HTML and JavaScript | Early design stage | **Architects**, planners, building contractors | Massachusetts Institute of Technology | http://apps1.eere.energy.gov/buildings/tools_directory/doe_sponsored.cfm |
| DOE-2 | Calculate energy performance and life-cycle cost of operation | PC-compatible; Sun; DEC-VAX; DEC-station; IBM RS 6000; NeXT<br>**Programming Language**:<br>FORTRAN 77 | Whole Building United analysis Programme | **Architects**, engineers, , energy consultants, building technology researchers, utility companies, state and federal agencies, university schools of architecture and engineering mainly in the US | James J. Hirsch & Associates (JJH) in collaboration with Lawrence Berkeley National Laboratory (LBNL) | Winkelmann *et al.* (1993); (Crawley et al., 2005); http://apps1.eere.energy.gov/buildings/tools_directory/doe_sponsored.cfm |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ecotect | Solar, thermal, lighting, acoustic and Cost analysis Functions | • Windows 95, 98, and XP (Can also run on Mac OS under Virtual **PC)** • **Programming Language: C++** | Comprehensive concept-to-detail sustainable building design tool | **Architects,** engineers, environmental consultants, building designers, and some owner builders mainly in Australia, UK and USA | Centre for research in the Built Environment (CRBE), UK | http://usa.autodesk.com/ecotect-analysis/ (Crawley et al., 2005) |
| eQUEST | Energy Performance | • Microsoft Windows 98/XP/Vista **Programming Language:** Interface: C++, DOE-2.2 engine: FORTRAN | Whole Building | All design team members including **Architects**, building designers, operators, owners, and energy/LEED consultants in US | James J. Hirsch and Associates | http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=575/pagename=alpha_list (eQUEST, 2012) (Crawley et al., 2005) |
| Energy 10 | Specifically designed to facilitate the evaluation of energy-efficient building features in the very early stages of the design process. | PC-compatible, Windows Pentium processor **Programming Language**: Visual C++ | Conceptual Stage Programming Language: Fortran 2003 | Building designers, especially **Architects**; also HVAC engineers utility companies and universities schools of architecture and Engineering (US) | National Renewable, Energy Laboratory (NREL) | http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=36/pagename=alpha_list (Crawley et al., 2005) |
| Energy Plus | Combination of DOE & Blast + additional features to model energy and water use in buildings | Windows, Macintosh, and Linux platforms | A whole-building energy simulation program | Architects, Engineers, and Researchers mainly in the US. | Developed by the U.S. Department of Energy (DOE). | (Crawley et al., 2000, Crawley et al., 2004, Crawley et al., 2005) |
| ESP-r | Public domain program/ General Purpose on energy and environmental performance | Sun-Solaris, Silicon Graphics: Sparc5 or newer, Linux, Mac and Windows Programming Language :C and FORTRAN (F77 or F90) Compiles with most Unix and Linux compilers | Early to detail stage | Engineers, researchers, energy consultants, multi-disciplinary design firms primarily in Europe and Asia | Department of Mechanical Engineering, University of Strathclyde | http://www.esru.strath.ac.uk/Programs/ESP-r_overview.htm (Crawley et al., 2005) |
| Integrated Environment Solution(IES) (IES<VE>) Virtual Environment | Integrated building performance analysis tools | | | Engineers, Consultants and Architects who are specialists in green buildings (UK) | Dr Don McLean IES, UK | http://www.iesve.com/ (Crawley et al., 2005) |

**Table 3.** Contrasting Capabilities of existing BPES tools

| Simulation Tools | Relationship to CAD | | Energy | | | Ventilation | | Weather Data | | Results | | | Validation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Import building geometry form CAD program | Export building geometry form CAD program | On Site energy emission | Major Green House Gas emissions (CO2, CH4, CO,NOX, | Energy and Demand charges | Natural ventilation | Windows openings for natural ventilation Controllable | With Programme (CD,DVD ,distribution download) | Separate | Standard | Users Define | Visual Surface Output (Walls, Window floors and roofs) | IEA ECBCS Annex1 | IEA SHC Task 12 Empirical (Lomas *etal.*1994) |
| **DOE -2** | | | x | x | x | | | | | x | | | | |
| **Ecotect** | x | x | x | | x | | | x | x | x | x | x | | P |
| **Energy 10** | | | x | x | x | | | x | | x | x | | | |
| **Energy Plus** | x | x | x | x | x | x | x | x(d) | x(d) | x | x | x | | x |
| **e-Quest** | x | | x | x | x | P(c) | | x(e) | x(e) | x | x | x | | |
| **ESP-r** | | x | x | x | x | x | x | x | x | x(a) | x | x | x | x |
| **IES <VE>** | x | x | x | x | x | x | X(b) | x | x | x | x | x | | x |

- x: Feature /Capability of tools
- P: Partially implemented feature
- a: Performance data is written in binary forms at four levels of detail
- b: Simulation variables to control same zone, other building zone,co2 concentration, external conditions(wind speed and direction, temperature)
- c: Simple schedulable operation window models
- d: Five weather files provided with more than 900 location available for down load in energy plus
- e:Automatically download weather files from web site
- f ;More than 1000 locations word wide

The core tools in the building energy field are the whole building energy simulation programmes that provide users with key building performance indicators such as energy use and demand, temperature, humidity and costs (Crawley et al., 2005). In general, simulation tools from Hong et al. (2000) can perform one or more of the following functions:

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

Thus, Table 4 categorised the BPES tools according to the specified stages of the design process the software developers marketed their applicability. From the Table 4, the support for the early design stage is poor, especially at the conceptual stage of the design process compared to the later stages within the table.

**Table 4.** BPES Tools for the different stages of the design process

| **Early Design Stage** | | **Detail Design Stage** | |
|---|---|---|---|
| **Stage A and B** | **Stage C** | **Stage D** | **Stage E** |
| **(Preparation Stage)** | **( Conceptual stage)** | **(Design Development Stage)** | **(Technical Design Stage)** |
| • Autodesk Green Building Studio<br>• Design Advisor<br>• Ecotect | • Energy 10<br>• Ecotect | • Building Design Advisor<br>• Ecotect<br>• Equest<br>• IES-VE | • Energy Plus<br>• ESP-r<br>• DOE-2<br>• Equest<br>• IES-VE |

There are many simulation tools, but most are less useful as design-decision support tools for architects. This is because; they tend to aim for greater degrees of accuracy, requiring larger amounts of data and user time, which by contrast, ‘*a useful design tool does not need to be highly accurate’* (Royal Institute of British Architects, 2009). Most of the simulation tools also address the needs of one specialism or specific phase of the design process. Subsequently, only a small minority of architects use the existing simulation portfolio to perform the evaluation of energy efficient strategies and technology options, at the crucial formative stages of the design process and the project at large. The building design process is a dynamic process of creating concepts that involve design strategies and technologies and then predicting and assessing their performance with respect to the various performance considerations within the specific design context (Hien and Poh, 2003). It is widely proposed that the use of simulation exercise at early design stage by simulation experts and non-experts like architects can influence better design of energy efficient buildings (Mahdavi and Silvana, 2003). However, Hopfe et al. (2009) states how practicing building performance simulation at an earlier point in time during the design process reduces the design iterations.

Within the building design community, there is, however, constant complains that BPS tools are not adaptive to the design process and its various phases; hence, they cannot be integrated into the design process (Morbitzer et al., 2001, Yezioro, 2008). Existing tools lack the capability to deal with the nature of the architectural design process because the tools do not match the design process (Lam and Wong, 1999, Ellis and Mathew, 2002).

Morbitzer (2003) acknowledged, it is the engineering consultants who are the regular users of computational tools, in comparison to the uptake of these tools by architects, which appears to be very limited. Dunsdon et al. (2006), survey of architects in Singapore, also came to a similar conclusion on how the usage of performance-based simulation tools for building design evaluation is rare, while De Wilde et al. (2002) state, '*very few tools offer some facilities that can be viewed as superficial first developments towards design decision support*'.

Ellis and Mathews (2002) attribute failure of existing tools to influence energy performance outcomes to the fact, '*they do not accommodate architects nor fit into the design processes*'. Morbitzer (2003) point out the reason for limited use of the simulation tools within the architectural design process, especially at the early design stage. He stated: '*Architects are seen as visual people and simulation being too abstract, thus, the role of energy analysis has been simply to give endorsement to a completed design rather than to assist the designer during the design process'.* Architects tend to follow an essentially iterative process and existing simulation methods had been to assess a completed design. He further observed that the major barrier to simulation programs being recognized as design support tools, to the same extent as CAD tools or costing software is because building simulation design is not fully integrated into the design process. This can also be related to the fact, '*architects tend to follow an essentially iterative process and the existing simulation methods assess completed design'* (Soebarto and William, 2001). "Energy performance has not traditionally been the concern of architects, but has been seen as a subsequent responsibility of service engineers, who are tasked with implementing an already formulated design" (Dunsdon, p. 4). On this note, De Wilde et al. (1998) observed that, since computer based energy analysis tools play a minor role in the selection of energy saving technology, simulation tools should '*adapt to the design process, and not vice versa'.* In a similar fashion, Mahdavi (1993) perceives that, if the crops of energy analysis tools are not being used to support critical early design decisions then the solution may be found in the use of tools that follow the design process.

However, in the recent time, building simulation discipline has been observed to be evolving and maturing with improvements continuously taking place (Hensen and Augenbroe, 2004). There has also been some advancement in developing architects friendly tools. This is exhibited in form of interoperability, where data can be transferred from architectural model to the simulation environment. Examples include the plug-in of IES (Integrated Environment Solutions,2012) and Energy PLUS for Google Sketch -Up, similar to the Revit Architecture plug-in IES and ECOTECT in addition to Energy Plugged that enables AutoCAD to create and edit Energy Plus input files(Energy Plus-Energy Simulation, 2013).

## 4. Method and results

Towards evaluating the state of- the- art of BPES tools, a total number of fifty-six (56) reviews (reference lists), including the resources from the homepages on some BPES tools were carried out (Tables 1 to 4). The reviews were combined with questionnaire survey analysis e-mailed to sustainable architectural practices in the UK, to form the basis for the evaluation in this paper.

A total number of 425 sustainable practices were selected randomly from the RIBA directory of architects to cover the whole geographical location in the UK. Thus, each architectural practice within the targeted population had an equal probability of being selected. The method used for selecting the 425 samples is from Creative Research Systems (2012), similar to Xiao (2002) and Ankrah (2007) to determine a suitable size for the sample.

### 4.1. Results

#### *4.1.1. Current use of BPES Tools by UK architects in stages of the design process*

From the sixty-two architectural practices representatives: 32.8 per cent use simulation tools such as Autodesk Green Building Studio (AGBS) and Massachusetts Institute of Technology (MIT) Design Advisor at the technical design stage; 31.3 per cent use such tools at the design development stage D of the RIBA Outline plan of work; 13.1 per cent use it at the concept stage C and 8.2 per cent use it at the preparation stages A and B. However, 11.7 per cent specified that they use such tools at all stages of their design, while 3.3 per cent responded that, they have not used (Not Applicable) such tools at all in their design (Figure 1).

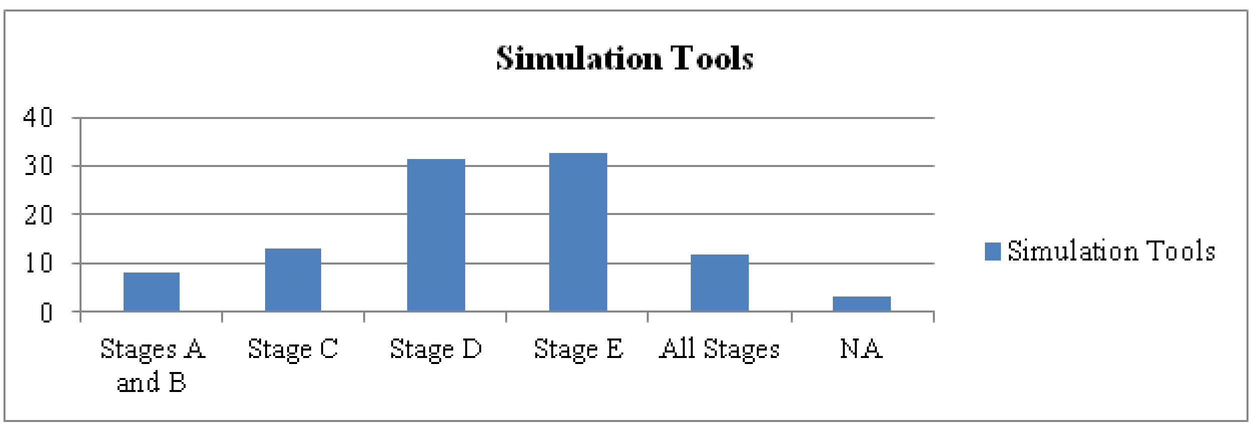


**Figure 1.** Use of BPES Tools in the design process

On the use of simulation tools such as Ecotect and Energy 10: 37.1 per cent use such tools at the design development stage; 33.9 per cent use it at the technical design stage; 8.1 per cent use such tools at the concept stage of the design process while none of the respondents uses it at the preparation stages A and B.

On energy simulation tools such as IES, eQUEST, Energy plus software, more than half (64.9 per cent) of the architectural practices acknowledged that they have not used such tools in their design. However, 15.8 per cent of the architectural practices had used it at the technical design stage, while 7.0 per cent responded that they had used energy simulation tools at all stages of the design process (Figure 2).

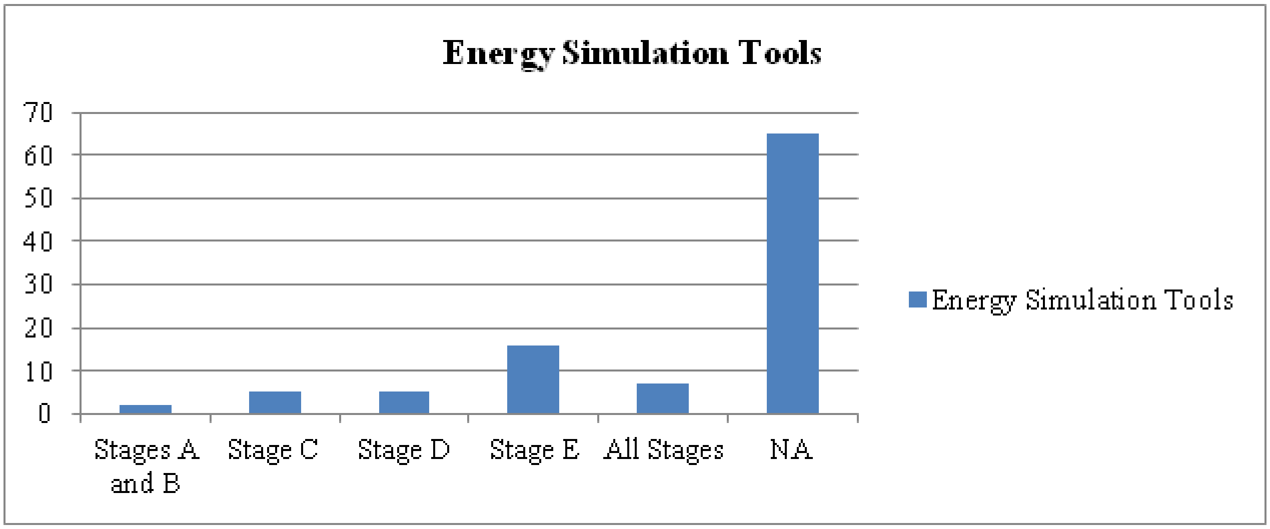


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**Figure 2.** Use of BPES Tools in the design process

## 5. Discussion

In addition to environmental considerations, a sustainable building with low impact design must also include economic and social aspects. Within the design process, architects are more concerned with design issues (such as geometry, orientation, aesthetic, natural ventilation and day lighting), while engineers are more concerned with mechanical systems and control; hence, the difference in the type of tools required by each profession. Although most of the BPES tools are specified for use at the early design stage, on the homepages of these tools and the software directory, the findings from the survey revealed that tools are used at the later stage of the design process. This is due to higher levels of accuracy and detail of data input required by most of these BPES tools, hence they are more appropriate for detailed stage of the design process. Thus, their unsuitability for the earlier design stage, especially the concept stage of the design process is poor.

Moreover, most of the tools are designed for engineers and poorly reflect architects' way of professional practice. This finding is, parallel to Attia and Beltran (2009) and Attia (2010) which stated that most of the tool developers use engineers' feedback to develop architect friendly tools. Consequently, most of the BPS tools are not suitable for the architectural design. "Existing BPES tools apply roughly the same theoretical algorithms and calculation aids, limiting representation of certain physical phenomena" (Ochoa Morales et al., 2012, p. 1). Although some models can be used for element design, they are not fit enough for architects' way of design-decision making. “Elaborate building components require separate analysis through complex simulation aids” (Ochoa Morales et al., 2012, p. 1). Few tools support the early architectural design process. Input quality affects accuracy, while output needs careful expert interpretation.

Moreover the newer software, which is attempting to address the well know failing of older software, sometimes by allowing AutoCAD to create and edit input files, the design process, especially the creativity stage of the process, needs to be well advanced before any of the BPES tools can be applicable, even the one marketed for the early design stage. Also, tools developers had not been stating the capabilities and limitations of the tools hence potential user is faced with difficulty of choosing a suitable program among the growing BPS tools pool. Apart from the expense of architects having to purchase the energy analysis tools and the plug in, which in most cases are on thirty days trial, problem has also been reported in the process of transferring data from the architectural models to the energy analysis software. Different methods of modelling are used in the different types of software, thus efficient exchange of geometric data is difficult and sometimes there is inconsistency in the geometry transfer between software packages. Hence, data may be lost or overwritten in the process of transfer between models or has to be re-entered. The whole building’s geometry must also come from the architects’ model, including: the number of rooms; the connections between rooms; their relationship to the exterior; exposure and aspect to the sun along with the shape and total area of built surfaces or openings.

## 5.1. Implication of the study

To deliver low impact buildings in the UK and fill the gap for architects to deliver the design, the loop between building design, operation and performance must be closed This will be especially important and useful at the early stage of the design process, where major decision that affects the building usually take place.

This can only be achieved by developing tools that follow the integrated design process. It should fit into architects’ way of design decision making. The tools developers should realise that to develop architects friendly tools, decisions are broad, at the early design stages and there is minimal concern for detail. tools for this stage, should allow the description and simulation of building in fewer minutes without extensive training on the part of architects. The results from such output should be in a form that can be understood even by non-experts and be able to give architects a quick and accurate output with minimum input. This is because, at this stage of the preliminary studies, the focus is mainly on the differences between different design alternatives, hence, calculations and all simulations should be performed quickly and effectively. Characteristics, such as degree in the flexibility, accuracy, data input, among others, should be taken into consideration when developing software tools for this stage. Hence, enough flexibility and low input information schema, amongst other requirements, are identified as being necessary in BPES tools for the early phase of the design process. As the project progresses, decisions become more refined as the focus is on very detailed aspects of the design. In general, data exchange at this stage needs to become more sophisticated, reliable and less error prone, so that practitioners can integrate these tools more smoothly into practice. Requirements of BPES tools targeted for this stage need to be more user-friendly, more capable, more robust, better documented, with minimal time for result output.

## 6. Conclusions

Since the field of BPS is vast, the purpose of this study was to clarify that field by emphasizing the state- of-the- art on BPES tools for architects' design and decision making, especially those that has been marketed for the early stage of the design process. The literature review and supporting survey conclusively posits that when simulation tools are used (if at all) in design and decision making by architects, their use is usually confined to optimization, verification and late in the design process, rather than at the early design stage where most of the important decisions relating to energy efficiency components are made. Thus, the role of energy analysis has been simply to give endorsement to completed designs.

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