International Journal of Sustainable Built Environment (2016) 5, 461–469

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International Journal of Sustainable Built Environment

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Original Article/Research

Building performance modelling for sustainable building design

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Received 2 April 2015; accepted 19 May 2016

Abstract

Sustainability has become a significant aspect of real estate and has been integrated into the design, construction and operation of buildings. Now, emerging from the various initiatives around the world, the building information modelling (BIM) approach has been seen as a method that might deliver substantial gains in terms of designing and assessing the environmental cost of buildings.

Various research methodologies have been adopted, including a literature review exploring the benefits and challenges of BIM and of using a building performance modelling software (BPM) called Ecotect for sustainable building design. Finally, it introduces a design tool analysis of a case study using Ecotect to evaluate various what if scenarios on a proposed multi-use building.

The output revealed that BPM delivers information needed for enhanced design and building performance. Recommendations such as the establishment of proper mechanisms to monitor the performance of BPM related construction are suggested to allow for its continuous implementation. This research consolidates collective movements towards wider implementation of BPM and forms a base for developing a sound BIM strategy and guidance.

Keywords: Building information modelling; Building performance modelling; Construction; Ecotect; Sustainability

1. Introduction

Recently, there has been a drive to discover how climate change and greenhouse gas emissions can be reduced (United Nations, 2007). Hence, the need for sustainable buildings as it is believed that buildings account for more than half of energy consumption and emissions (Berardi, 2013). Luckily, recent research has also supported the existence of a robust business case for sustainable buildings (Walker, 2015; Davies, 2005).

Existing methods such as the life cycle assessment (LCA) and life cycle costing (LCC) have been used to determine the environmental and economic costs of these buildings throughout its entire service life including the disposal cost (Dhillon, 2013; El-Haram et al., 2002). However, where LCA and LCC are performed and used together, by the same persons, using the same software, with the same databases, and in an integrated way, inconsistencies between the two underlying tools will provide a barrier in terms of efficiency, reproducibility and transparency.

Hence the need has arisen to embrace the building information modelling (BIM) method as it covers the architecture, information technology and construction. BIM is a set of interrelating strategies, procedures and skills that

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Peer review under responsibility of The Gulf Organisation for Research and Development.

http://dx.doi.org/10.1016/j.ijsbe.2016.05.004
2212-6090/

creates a framework to monitor the vital building design and display data in digital layout throughout the building's life-cycle (Penttilä, 2006).

Thus, it's relevance among all built environment professionals as it has turned out to be a dynamic research area of sustainable building design. Similarly, building simulation is gaining extensive use as a cost-effective technique of supporting energy efficient design and the subsequent operation and maintenance of buildings (Wang et al., 2015; Bryde et al., 2013). These simulations include the assessment of the performance of energy-saving methods and architectural concepts (Monteiro and Martins, 2013).

While there has been significant progress on the application of BIM in sustainable building design as seen in Smith (2007), most research work has also emphasised on the analysis of energy usage as seen in Niewoehner (2010). Similar work showed how BIM could be used to promote sustainable building design with particular emphasis on the mechanical and electrical sections of buildings (Middlebrooks, 2008) and also the contribution of solar analysis to energy saving (Wong and Fan, 2013).

Further research work considered the thermal analysis of a building block containing phase change material (Alawadhi, 2008), the finite-volume thermal analysis of building roofs under two dimensional periodic conditions (Al-Sanea, 2003) and thermal analysis and design of passive solar buildings (Athienitis and Santamouris, 2013).

However, no research work has introduced BPM enabled sustainable design with emphasis on thermal analysis of a simulated conference hall which incorporates various indices of sustainability by exploring several what if scenarios to determine which design parameters/configurations can be combined to achieve a low energy and self-sustaining building.

This paper discusses BIM and Ecotect's benefits and challenges and provides recommendations on how to apply BPM to sustainable building design. This would allow researchers to be more confident in demonstrating the relevance of sustainable design analysis tools in meriting sustainable design criteria.

2. Research methodology

This research begins with a review of the literature on BIM and sustainable design. It also investigates the challenges of BIM and the limitations of Ecotect in sustainable design and then proceeds to conduct a design tool analysis of a simulated case study.

Building performance modelling (BPM) is the use of software to predict the energy use of a building (Volk et al., 2014). It is the attempt to model the various energy and mass flows within a building in order to forecast one or several performance aspects of a building using computer simulations (Arup, 2013; Tao and Tam, 2013).

The models provide a simplified illustration of the features of our environment in order to use performance to inform design. The initial sketch of the model applied was experimented using sensitivity analysis in order to achieve a sustainable design alternative at the design sketch stage when the cost of change to project is at the least.

3. BIM in sustainable design

BIM has deservedly received so much attention in recent years and is very useful in performing sustainable building designs (Wang et al., 2015). BIM provides important data and information for design projects and also encompasses several important functions for building performance analysis. Consequently, studies around sustainable building design have become more methodical in nature (Liu et al., 2015).

With the help of BIM, designers can foresee and envisage the likely errors in design and subsequently adjust the designs early in order to reduce the possibility of project failure. Consequently, BIM has become a common tool used for sustainable building design. It simulates building projects in the virtually visible environment and incorporates all associated information include geometry, spatial relationships, geographic information, and quantities and properties of building elements (Hoes et al., 2009). It provides an ability to do the simulation for validating the performance of design projects and enables designers to improve their designs and select the optimal one.

4. Challenges of BIM application in sustainable design

The use of BIM in sustainable design requires significant training and as with many software programmes, there are huge costs associated with purchasing, licensing and training (Bynum et al., 2012). A contractor may need to upgrade its computer system to effectively use the BIM software. Adequate training is needed in different areas, and levels of expertise can vary (Wang et al., 2015).

Furthermore, BIM requires more effort at the outset of a sustainable design project (McAdam, 2010). When BIM is used, it is insufficient for a contractor to simply submit plans for its own work and then begin construction. The contractor must first sit down with the designer and other contractors associated with the project to create a collaborative model (Sawhney and Singhal, 2013).

Although one of the advantages of using a BIM model is that changes can be made quickly, BIM can disrupt the general procurement and construction process when ordering items that require a long lead time (Manning and Messner, 2008).

5. Design tool analysis

The following steps are used in this paper to develop a BIM enabled sustainable design conceptual framework with emphasis on thermal analysis.

(i) Site description.
(ii) The building.

(iii) Selection of sustainable design indicators.
(iv) Baseline analysis for summer and winter solstice.
(v) Running what if scenarios using improved roof insulation, improved glazing type and insulation to window and internal gain and occupancy level.
(vi) Analysis using sensitivity analysis for varying number of occupants and activity level.

5.1. Site description

The proposed development (Figs. 1 and 2) is located in the northern part of Derby city centre in the East Midlands and bounded by St. Alkmund's Way (inner ringroad), the River Derwent, Exeter Place and Darwin Place, a total area of 2.31 ha (5.7 acres). Currently the site is a surface car park (Darwin Place) and the river frontage land is occupied by a block of flats (Exeter House). The area is meant to be redeveloped and integrated back into the city centre.

5.2. The building

The facility is a multi-use building; named 'the waterfront and the proposal consists of a self-surviving conference and multi-purpose hall (Fig. 3).

5.3. Selection of sustainable design indicators

In order to evaluate energy and resource efficiency, waste prevention, pollution management and so on among other indicators of sustainability at the early stage of design, various energy performance analysis tools are available. Currently, there are three commonly used BPM-based sustainability analyses software available to the researcher. These are: Autodesk Ecotect, Autodesk Green Building Studio (GBS) and Integrated Environmental Solutions (IES) Virtual Environment (VE).

For the purpose of the paper, Ecotect was used as the building performance tool. It is compatible with BIM software, such as Autodesk Revit Architecture. Various studies have demonstrated that Ecotect simulations are highly accurate (Vangimalla et al., 2011; Abdullah et al., 2013). It is used to perform comprehensive preliminary building energy performance analysis (Wang et al., 2011). The analysis software combines an intuitive 3-D design interface with a comprehensive set of performance analysis functions and interactive information displays.

It also provides thermal, lighting and acoustic analyses, including hourly thermal comfort, monthly space loads, natural and artificial lighting levels, acoustic reflections, reverberation time, project costs and environmental impact (Marsh, 2003; Crawley et al., 2008).

These Ecotect simulations are complimented by various architectural practices which help in achieving design that is capable of reducing global warming potentials in the building. It can also result in substantial reduction in operation costs of the building.

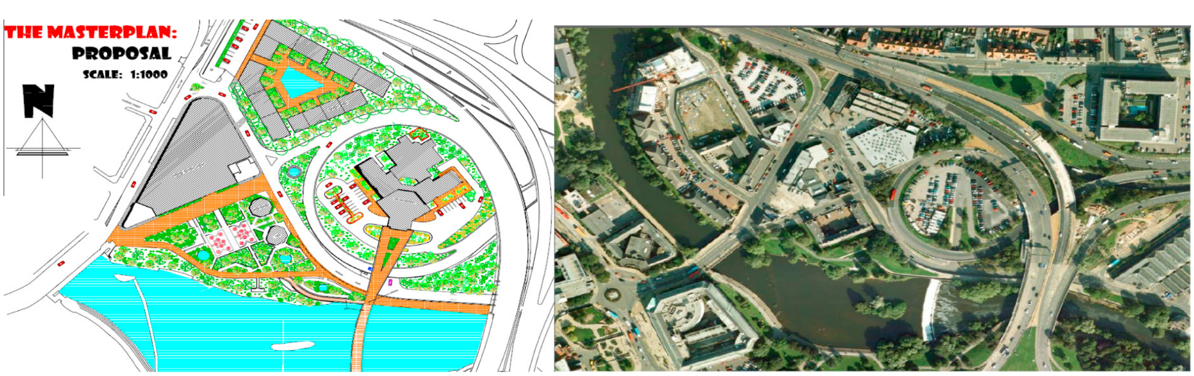
5.4. Analysis and discussion of results

This section covers the fourth to sixth step in the schematic conceptual framework. Thermal analysis was performed in this sustainable design analysis (SDA) to ensure that the space is thermal efficient enough and requires little or no heating and/or cooling. This was executed by using various sensitivity analysis based on materials change to shift the indoor thermal level into the range of 180–250 °C temperature which is generally referred to as comfort zone (Abdullah et al., 2013).

5.5. Baseline analysis for summer and winter solstice

The initial analysis before the exploration of various what if scenarios was carried out for the two extreme ends of the weather, summer solstice and winter solstice and the results are given in Figs 4 and 5.

From the above result (Fig. 4) for 21st December and 21st June (Fig. 5) were derived. It was observed that the indoor temperature varies with the outdoor weather for the main hall area. The temperature is as high as between 22 and 330 °C on 21st June, and as low as between 11 and 140 °C in the winter solstice.



Figures 1 and 2. Master plan proposal and Site location plan. Site location: longitude: 1028.55′W, latitude: 52055.32′N. Meanwhile, the nearest available weather data for this sustainable design analysis is that of Birmingham which is located at: longitude: 1°54′36″W latitude: 52°28′48″N.

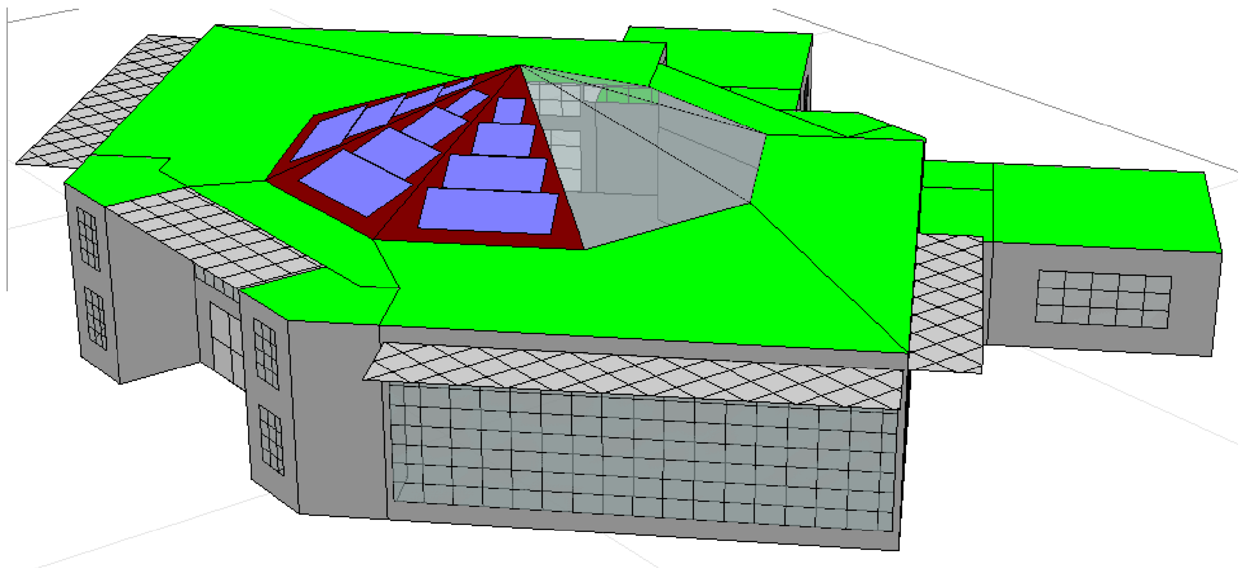


Figure 3. The proposed conference hall.

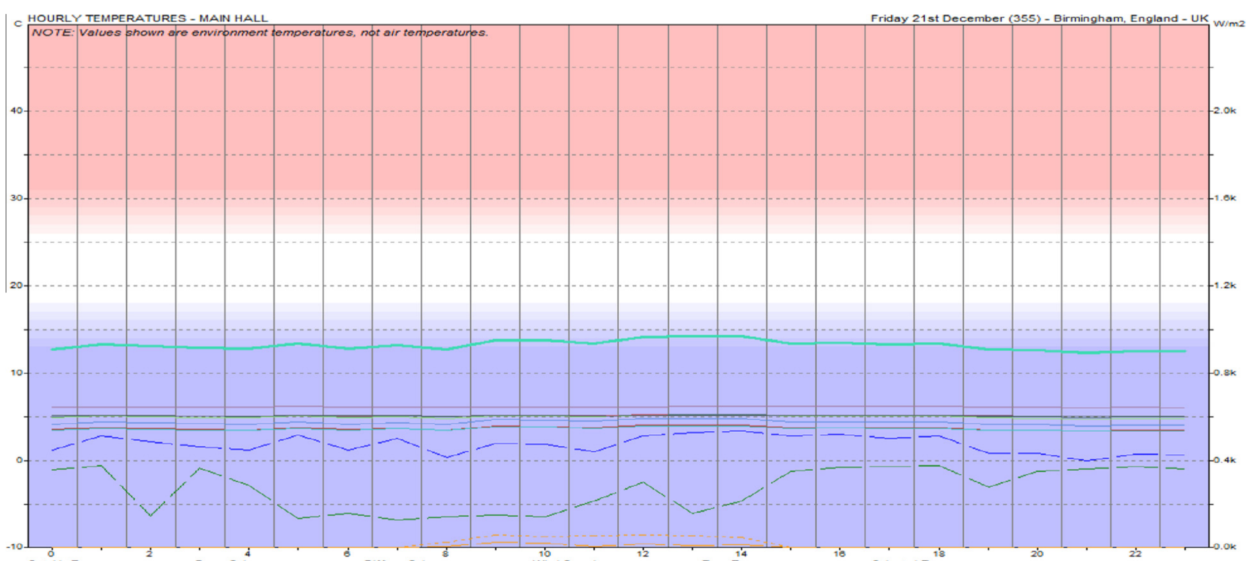


Figure 4. Thermal performance of the hall in the winter solstice.

Various options were explored, some of them are considered as adoptable while some would still result in excessive energy use. For instance, reducing percentage glazing would substantially reduce heat gain/loss, but it would also result in excessive energy needed for lighting. Therefore, improving thermal quality of the glazing insulation was rather considered.

5.6. Running what if scenarios for improved roof insulation

Insulation to the flat roof was improved from fibre slag to cellulose insulation and the roof insulation thickness was changed from 100 mm to 240 mm. The main roof was also changed from metal deck to metal deck insulated with an improved loft thickness of 300 mm fully insulated. This resulted in less change to the thermal quality of the space; however, hourly thermal gain was reduced from 4800 W to 2700 W (see Figs. 6 and 7).

5.7. Running what if scenarios for improved glazing type and insulation to window

Window type was changed from double glazing to triple glazing with 2 low-E panes; careful attention was given so that the new glazing type will not affect illumination level as glazing type determines transmissivity level (see Figs. 8 and 9).

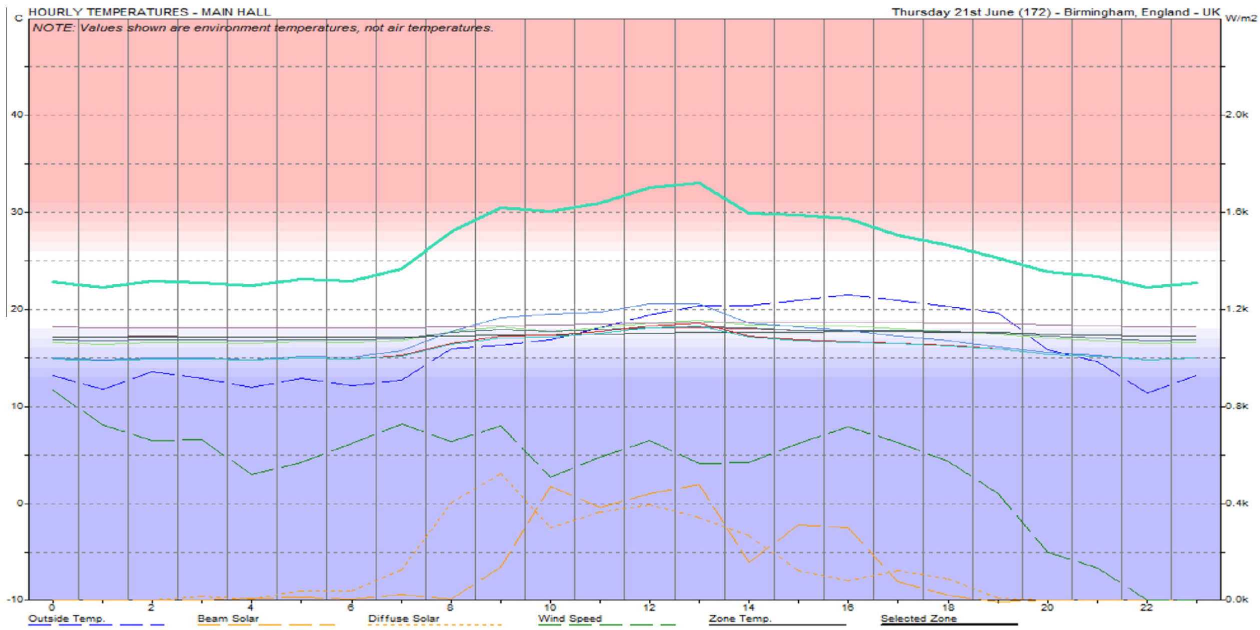


Figure 5. Thermal performance of the hall in the summer solstice.

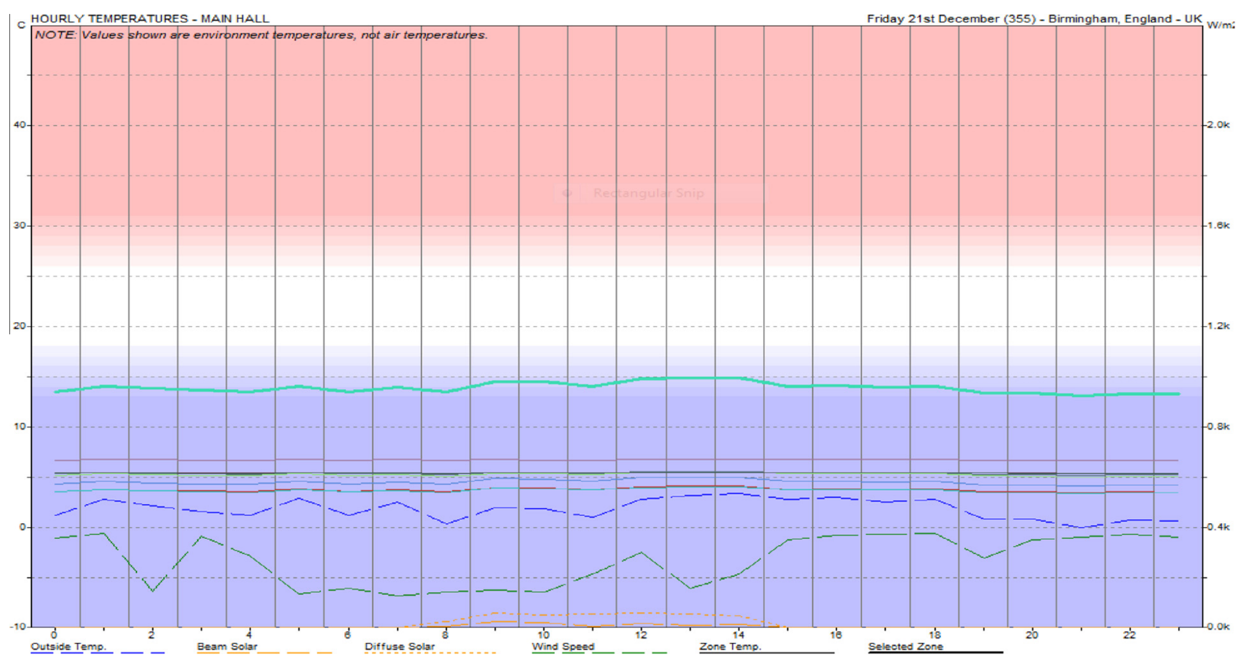


Figure 6. Less changing effect of improved roof insulation for 21st December.

As shown in Figs. 8 and 9 above, improved window thermal qualities resulted in thermal comfort during the cold months ranging from October to April months while it still does not fall within the comfort zone from May to August months as the temperature ranges between 26 and 320 °C.

5.8. Running what if scenarios for internal gain and occupancy level

The hourly heat gains suggest that excessive indoor temperature above thermal comfort within the space is due to internal gain; although this is slightly reduced with material and insulation change as shown in Fig. 10.

5.9. Further analysis using sensitivity analysis for varying number of occupants and activity level

This source of the heat gain is examined by further tracing its causes using various sensitivity analyses such as varying number of occupants and activity level. The result shows that using 400 number of occupants at normal activity level, the building would require some level of cooling from May to August months while no heating would be

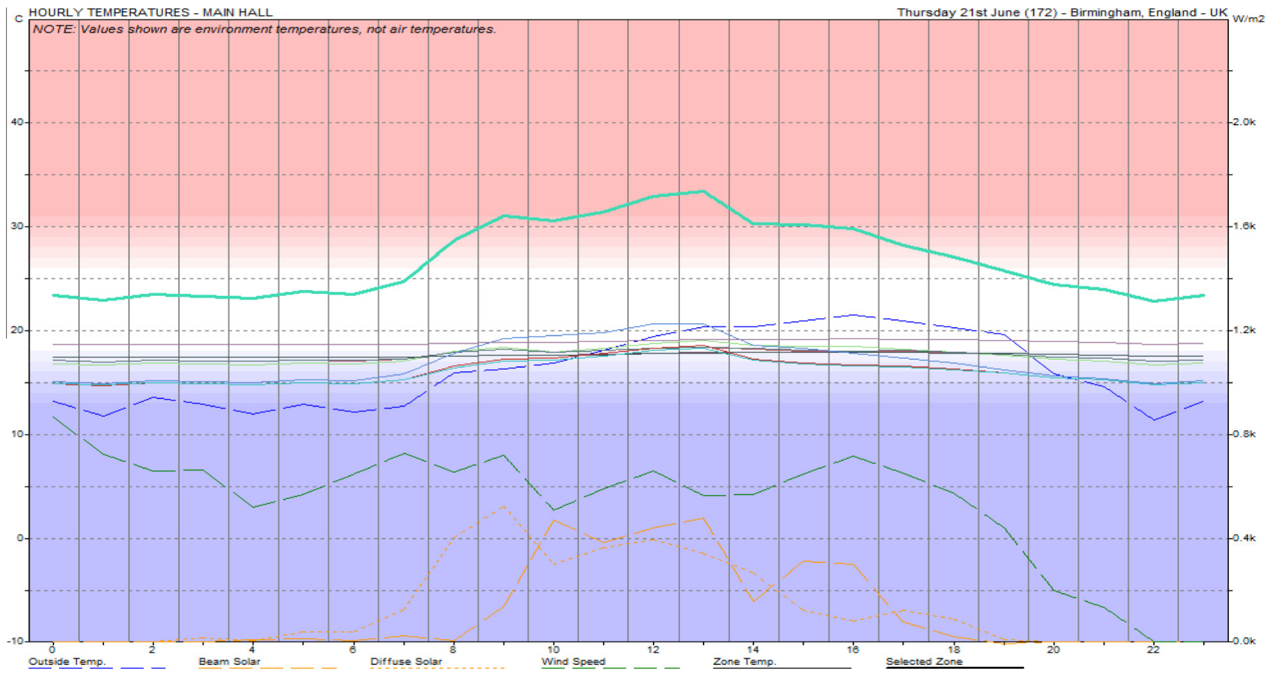


Figure 7. Less changing effect of improved roof insulation for 21st June.

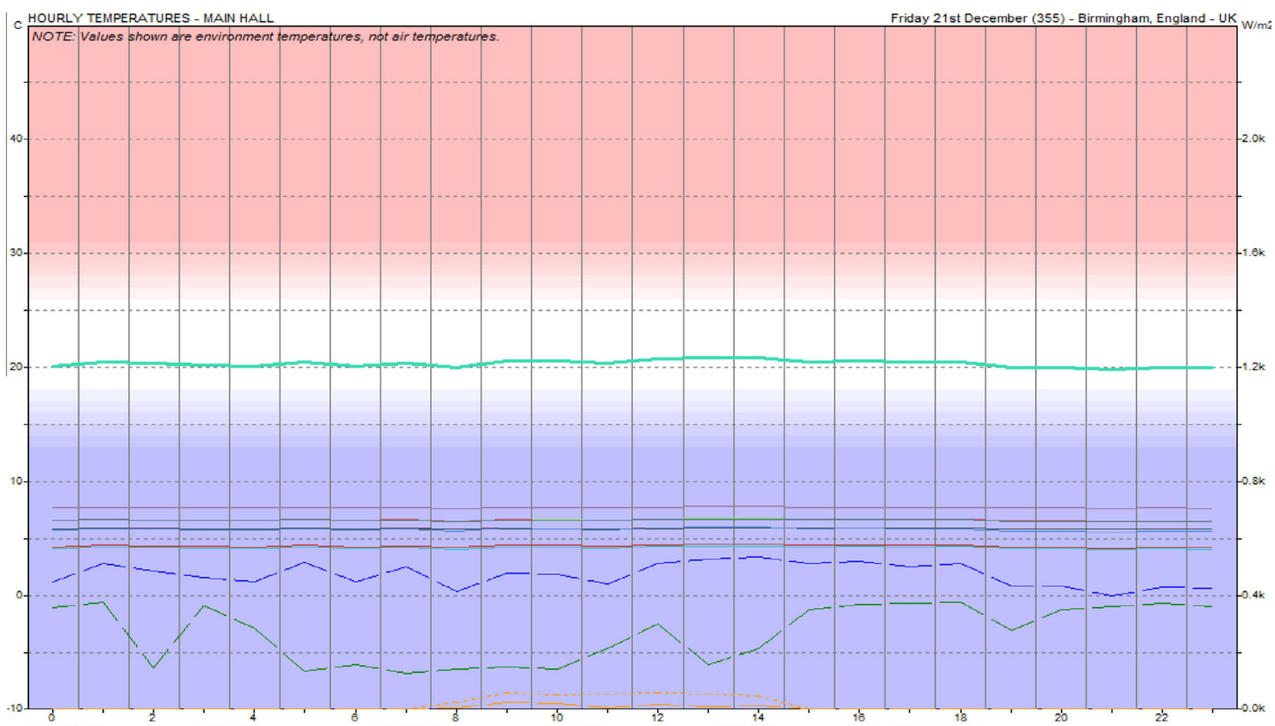


Figure 8. Thermal comfort effects of improved window quality for 21st December.

needed throughout the year whether the hall is at the full capacity level or not (see Fig. 11).

Fig. 11 shows that thermal comfort would be achieved in summer months when the number of occupants is reduced. However, as cooling is synonymous with buildings with higher number of occupants, especially during summer months, the simulation points to the fact that buildings will require some forms of cooling installed.

This would only be required when the space is filled; otherwise, it will remain within the comfort band throughout the year. Hence, this shows that based on design, shading and material selection, the space is in itself thermal

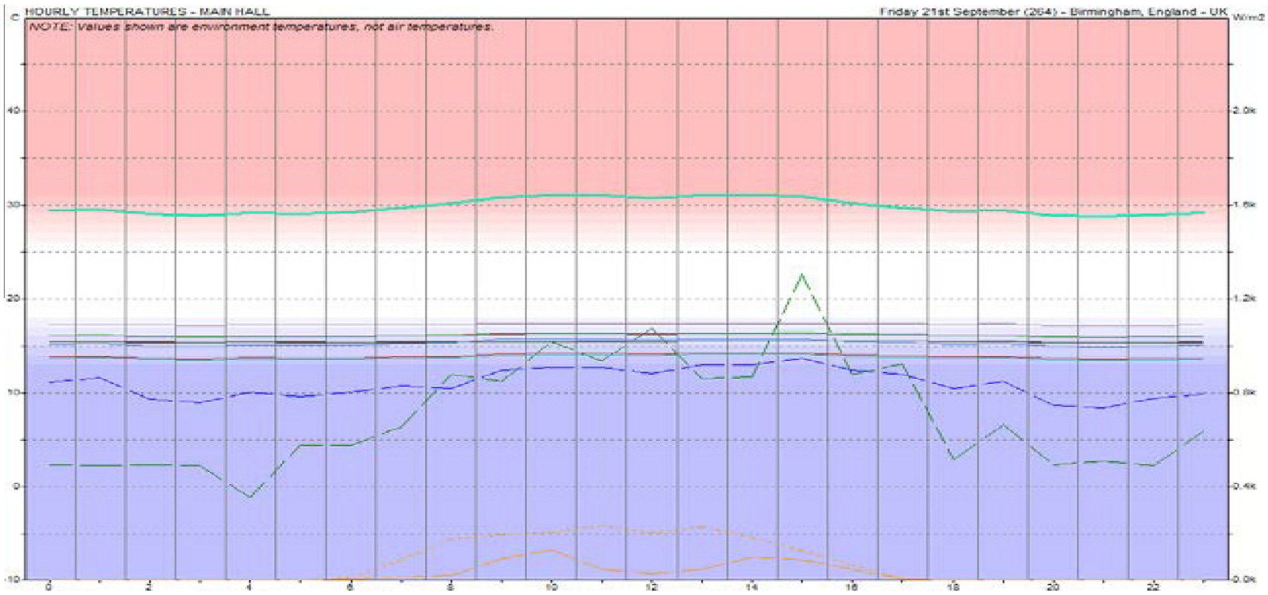


Figure 9. Less thermal comfort effects of improved window quality for the winter period.

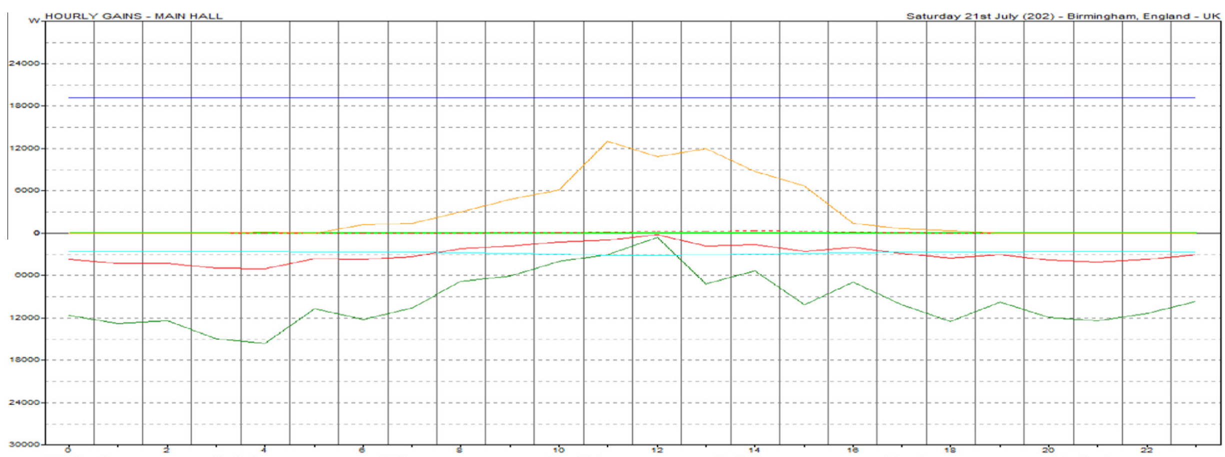


Figure 10. Hourly heat gains suggesting that thermal comfort is not achieved in summer due to heat gain from within the zone.

efficient. The need for cooling during summer months would be determined by occupancy and activity level.

6. Limitations of Ecotect

(1) Data availability and quality for the early design phases are limited when detailed energy-use models have not been created. Consequently, multiple data sources are used and an increased number of assumptions were introduced. This drawback is being ameliorated as databases begin to store more information (Peng, 2015).
(2) Another unresolved issue in thermal analysis of the buildings is the identification of benchmarks. Benchmarks are important in building performance studies because they provide a basis for comparing the performance of a given project under consideration (Bayer et al., 2010). Ecotect is composed of simplified energy modelling tools that are based on more complex simulation engines and thus cannot be used for meeting codes or regulations.
(3) Another limitation is the programme's long run times. Reducing the time requirements for a thermal analysis could potentially allow designers to check the impacts of their designs earlier.

In summary, the study has been able to demonstrate that sustainable design analysis tools can immensely help designers to achieve good environmental rating, low carbon house, lower life cycle cost and so on, if various what if scenarios (sensitivity analysis) are properly evaluated at the early stages of design when the cost of change is at the cheapest. The study has also discussed the concept of

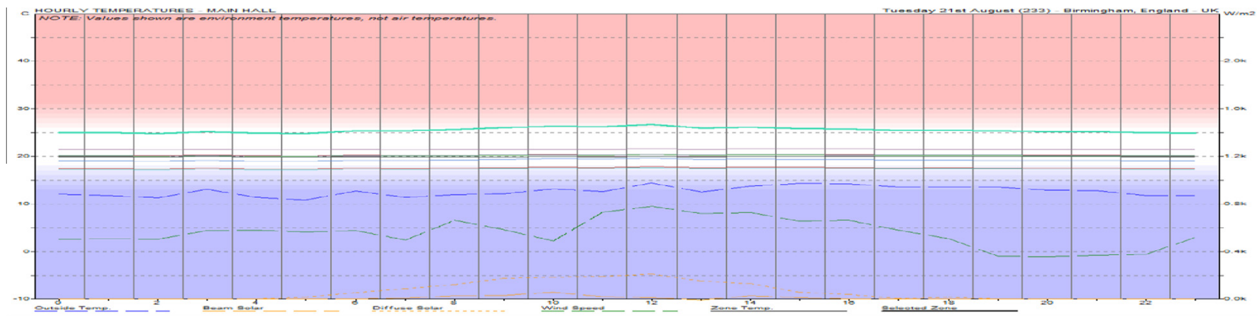


Figure 11. Thermal comfort achieved with reduced number of occupants from 400 to 200.

BIM in sustainable design and the challenges of BIM and Ecotect application in sustainable design.

7. Recommendations and conclusion

The research has been able to demonstrate the relevance of sustainable design analysis tools such as Ecotect in meeting sustainable design criteria. The simulated conference hall with the help of the sustainable design tool incorporated various indices of sustainability by exploring several what if scenarios to determine which and which design parameters/configurations can be combined to achieve low energy and self-sustaining building. There is however a need to apply BPM to daylight analysis, artificial light visual simulation, visual impact studies and environmental cost impact analysis as these enhance its significance.

The application of building performance modelling (BPM) has demonstrated enormous potential to deliver consistency in the construction collaboration process. BPM can define an explicit configuration for digitized information exchange, however the technology to collaborate on models has not yet delivered the industry requirements for its collaboration. There is a need to speed up development and standardization of BIM sub models to provide for broader coverage of user requirements and information flows in the full lifecycle of projects.

Any BIM standards must ensure collaboration and continuing commitment among the participants. The involvement of numerous stakeholders causes organisational problems and imposes the need for consistent highlighting of the "win–win" outcome for the participants over and above any individual and conflicting interests. Effective management and administration of the BIM standard roll-out is therefore necessary for marketing and for spreading information, so that the standards becomes widely known and accepted in the industry.

Finally, BIM has the potential to become the leading technology of the building industry, and it is in the interest of most firms to begin their conversion towards its processes. The more BIM is used, and the more data that are collected and stored during the life of a project, the more benefits can be leveraged. As users gain proficiency with BIM, they will increasingly benefit from the technology's potential and push for new ways to gain advantages in every area of the project.

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