Energy 97 (2016) 517–527

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling)

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ARTICLE INFO

Article history:
Received 11 July 2015
Received in revised form
14 December 2015
Accepted 30 December 2015
Available online 2 February 2016

Keywords:
BIM (building information modelling)
Building orientation
Energy
Green Building Studio
Small-scale construction
Sustainability

ABSTRACT

BIM (building information modelling) has developed into a powerful solution that can improve many aspects of construction industry. Current research regarding the impact of orientation on a building's energy needs seldom tap into the potential of BIM. This study investigates the impact of orientation on energy consumption in small-scale construction, and assesses how BIM can be used to facilitate this process. The methods adopted are three-fold. Firstly, a real-life building is modelled using Revit, one of the leading BIM tools. Secondly, through green building Extensible Markup Language, the model is exported to Green Building Studio, one of the leading energy simulation software. Thirdly, in the Green Building Studio, different building orientations are adopted and their impacts of the whole building energy are investigated. Based on the analysis of the energy consumption corresponding to the different orientations, it emerged that a well-orientated building can save a considerable amount of energy throughout its life cycle. Specifically, a total electricity use difference of 17 056 kWh and a total gas use difference of 27 988 MJ leading to a combined energy cost savings of £878 throughout a 30 year period between the best (+180°) and worst (+45°) orientations of the building was achieved.

1. Background

According to the recent the IPCC (Intergovernmental Panel on Climate Change) AR5 (Fifth Assessment Report), globally buildings were responsible for about 32% of energy consumption and emission of 19% of energy-related greenhouse gases in 2010. These shares impact negatively on the environment and communities through global warming. With growing threats of global warming, it is not a surprise that the construction industry is now beginning to address the need for energy efficient buildings [17].

There are several factors that can influence the energy needs of a building, many of which can be managed to improve building energy efficiency. According to the International Energy Agency [30]; the energy performance of the building envelope and its components (external walls, roofs, windows etc.) can be critical in determining how much energy is required internally. Studies have suggested that lower energy consumption can be due to improved insulation and more efficient building elements [18,59]. Occupants' behaviour is suggested to impact the level of energy required for space heating in dwellings [3,37]. For example, the use of heating systems, space and appliances will differ significantly between occupants with dissimilar behaviour [53]. The shape and size of a building can have an impact on energy consumption [5,20,24,25]. Catalina et al. [20] suggested that in order to minimise heat loss, a compact shape (e.g. a cube) is required. The ability that a building has to use solar radiation for heating and lighting may influence energy efficiency, which is often determined by building orientation. As suggested by Wong and Fan [63]; it is vital to correctly orient a building so that it can receive a large solar contribution. The use of heating and lighting systems are two major factors that influence energy consumption in buildings [40], both of which relate to building orientation. In order to maximise solar gain (which is important during colder seasons), it is vital to correctly orient a building so that it can receive a large solar contribution [19,63]. Among the parameters that have an impact on passive solar gain, Morrissey et al. [42] identifies orientation as one of the most important. Pacheco et al. [49] claims that building orientation is one of the greatest repercussions on the energy demand of a building. Furthermore, Aksoy and Inalli [10] suggest that the

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http://dx.doi.org/10.1016/j.energy.2015.12.135
0360-5442/

optimisation of both building orientation and shape can lead to energy savings of 36%. Spanos et al. [56] argue that good orientation, location on site and landscaping changes may potentially reduce the energy requirements of a building by 20% through increasing the quantity of daylight entering an internal space. Fallahtafti and Mahdavinejad [25] investigated the impacts of 16 different formations of buildings against a fixed orientation. Xu et al. [64] used EnergyPlus to only analyse the energy saving performance by optimizing buildings' orientation of some representative cities in China. Al-Fahmawee [11] use mathematical techniques such as linear regression models to determine the impacts of different floor heights and building orientation on atrium daylighting levels.

Based on the review in the preceding paragraph, it is important to note that most studies have grounded evidence of impacts of orientation on building energy consumption. However, from methodological and technical points of view, many studies used techniques that are still too slow with higher chances of making errors in the process of computations. For example, Al-Fahmawee [11] is based purely on mathematical techniques that limit the chances of performing many real time changes about different options that can allow end-users to choose amongst the options. Furthermore, all the afore-mentioned studies about orientation on building energy performance have focused on limited number of orientation variations. Unfortunately, opportunities and capabilities enshrined in emerging BIM (building information modelling) are often being missed due to the lack of knowledge about the potential BIM in assessing the impact of building orientation on building energy efficiency.

Emerging BIM can allow professionals to virtually learn the impacts of orientation on building energy efficiency before a single brick of the building is laid on site. This can allow professionals and end-users to make so many alterations virtually and then making decisions about the various options. The novelty of this study lies in the integration of BIM systems and their use in virtually investigating the impacts of multiple orientations on building energy consumption.

Having examined the limitations of current studies and impacts of building orientation on energy consumption, the aim and objectives of this study will be discussed in Section 2. Section 3 will dwell on the research methods adopted to achieve the stated aim and objectives. In Section 4, an overview of BIM will be provided. Section 5 will dwell on the relationship between BIM and energy simulation software systems. In Section 6, the rationale or justification for choosing the different software used in this study will be discussed. Based on the chosen software in Section 6, a case study application implemented in the chosen software is examined in Section 7. In Section 8, the results, analysis and discussions will be presented. In Section 9, the results are validated using both another energy simulation software and real data from an existing energy bill. In Section 10, the opportunities and challenges in the building energy simulation process are discussed. The paper concludes by a way of summary in Section 11.

2. Aim and objectives

The aim of the study is to investigate the impact that building orientation has on energy use within small-scale construction using emerging BIM. The research objectives are to:

- explore BIM software and energy simulation systems for modelling building orientation for the purposes of energy analysis;
- investigate the impact of building orientation on energy consumption using appropriate BIM software systems
- investigate the opportunities and limitations involved in the analyses of the impact of building orientation on energy consumption in a BIM/energy simulation software environment.

3. Research methods

A number of research methods were chosen, each or a combination of more than one was/were tailored to meet specific research objective(s). To facilitate understanding the research framework will be presented in Fig. 1.

The first step consists of undertaking an extensive literature review about the different domain relevant to this study. Specifically, factors that affect building energy use, BIM and energy analysis software are reviewed. This led to the understanding of nexus between building energy orientation and building energy consumption. Furthermore, an extensive review of BIM and energy analysis software was conducted to establish their suitability for use in this study. Main literature sources for the review include material from vendors' websites and peer-reviewed publications [1,2,7–9,15,22,34,48,54,61]. Secondly, based on the different software identified in the previous step, their uses in modelling of building and energy simulation are investigated. The details of the simulation steps are indicated in Fig. 1. Thirdly, based on the preceding step, the simulation processes are implemented on a chosen case study building with well-known information. Choosing a building with well-known and established characteristics is important as it allows authors to easily analyse and interpret findings from iterating the different modelling of building orientations. This allowed for an in-depth analysis of the potential in modelling building orientation in a BIM environment. To ensure the computational results are accurate, a second software is used to verify the results. Fourthly, based on the case study analysis, one of the computed results is compared with data from a real energy data, in this case a bill. This some sort, serve as a validation of the whole computation.

4. Building information modelling: what is it?

Construction projects are becoming more complex and difficult to manage [12,21,62] and as technology develops, more construction professionals are familiarising themselves with BIM. This has led to a dramatic shift in attention towards the concept of BIM by the construction industry. BIM is currently the most common denomination for a new way of approaching the design, construction and maintenance of buildings [16]. It is the creation and use of coordinated, consistent, computable information about a building project - information that is parametric and that can be used for design decision-making, production of high-quality construction documents, prediction of building performance, cost estimating and construction planning [33]. BIM is a set of policies, processes and technologies integrated as a methodology to manage the essential building design and project data in a digital format throughout a building's life cycle [57]. Froese [26] argues that in the near future, BIM will be used to virtually construct an entire project through simulations before it is erected or constructed in reality. The fact that BIM can be used to model buildings and for analysis to be performed virtually before the buildings can be erected onsite is one of the most important strengths of BIM. It is this aspect/feature that has been exploited in this study. BIM software packages are highly needed for the development/design of the virtual building models. The urgent need to incorporate BIM in managing construction information has led to a plethora of BIM software packages in the market. Some leading and most common BIM software packages have been reviewed in Kurul et al. [34]; Abanda and Tah