

PAPERS PRESENTED ON RESEARCH TOPICS

A Building LCA Case Study Using Autodesk Ecotect and BIM Model

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The main objective of this study is to evaluate the potential of utilizing building information model (BIM) to perform whole building Life Cycle Analysis (LCA). The research question addressed was how life cycle performance of a building was affected quantitatively by design configurations. Life cycle energy consumption and CO_2 emission of a university building in the Midwest was calculated using Autodesk® Ecotect and BIM model. The study compared life cycle performance, i.e., CO_2 emissions and energy consumptions, among different design configurations, as well as their distributions in the stages of the building's life time. Sensitivity analysis was performed by changing several alternative parameters, to identify which parameter has more impacts on building performance. Preliminary results indicated that whole building life cycle performance is affected by several design parameters, with different degree of sensitivity. The conclusions of the study are: 1) The combination of Ecotect and BIM model provides a convenient tool to conduct whole building LCA through the easier data flow from the BIM model to Ecotect. The data entry workload for whole building LCA can be reduced significantly. 2) Energy consumption in the operating stage dominates the lifecycle energy consumption of the building. 3) Sensitivity analysis of impact of design change can be conducted using the combination of Ecotect and BIM model.

Key Words: Building LCA, BIM, CO_2 Emission, Energy Consumption, Case Study

Introduction

The building sector has been identified as a major contributor to global environmental impact due to human activities (Zabalza Bribián et al. 2009; Junnila and Horvath 2003). The building sector accounts for about 40% of the total energy consumption and 38% of the CO_2 emission in the U.S. (DOE 2009). Life cycle assessment (LCA) has been used in buildings/construction sustainability assessment since 1990 (Fava 2006). LCA has been applied at different levels in building systems, such as building materials, building products, or the whole building (Erlandsson and Borg 2003). Most building related LCA studies focused on the specific part of the building life cycle, few of them addressed the whole building in its life cycle (Ortiz et al. 2009) due to the difficulties to acquire accurate quantities of building materials and building performances, especially in the design stage. The BIM model provides an effective platform to overcome the difficulties of acquiring the necessary building data in LCA. And thus, it provides great potential for conducting whole building LCA in the design stage. The building in this study (Figure 1) has three floors and a basement. It is located on a university campus with the initial building cost $8.7 million, including student offices, tutoring rooms and areas for faculty, staff and students dedicated to diversity and multicultural programming. The general information about this building is listed in Table 1.

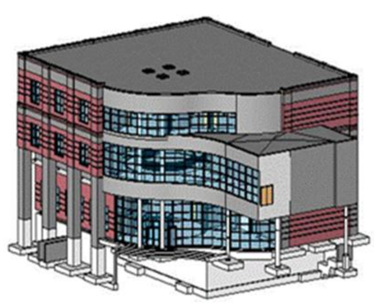


Figure 1: the BIM model used in this case study

The main objective of this case study is to evaluate the potential of using the BIM model to perform whole building Life Cycle Analysis (LCA). The life cycle energy consumption and CO_2 emission of a university building in Midwest was calculated using Autodesk Ecotect and the BIM model of the building.

Table 1

The general description of the building

Basic parameters	**Specification**
Location	Midwest
Gross floor area	34,313 SF
Building height	68 feet
Structure	Steel frame
Envelope	Brick/CMU and curtain wall
Indoor temperature set	64 ºF -78 ºF (18°C-26°C)

The study compared lifecycle performance, i.e., CO_2 emissions and energy consumption, among different design configurations of the building. Sensitivity analysis was performed based on several alternative designs in this study to see their impacts on the building performance. The following research tasks were carried out in this study: 1) Examined energy consumption and CO_2 emission of a newly constructed university building from a lifecycle point of view, 2) Compared energy consumption and CO_2 emissions among different design scenarios, and 3) Investigated the sensitivity of life cycle energy consumption and CO_2 emission to chosen factors.

Research Approaches

This case study combined three types of methods to perform the case study. Firstly, life cycle modeling of the building was executed based on its physical process from cradle to grave. BIM and Ecotect were then used to provide required information and tools for simulating the building performance. In order to see the effects of some chosen factors on building performance, design configurations were changed through an imaginary way.

Life cycle modeling: The full building life cycle usually includes five stages: raw materials and manufacturing, construction, operation, maintenance, demolition (Seo and Hwang 2001; Kofoworola and Gheewala 2008). In this study, demolition stage and maintenance stage were excluded due to their lower weight in importance (Sartori and Hestnes 2007).The BIM Model was used to provide material quantities and specifications. Detailed analysis can be seen in the following section.

Building performance simulation: Ecotect is an energy simulation tool, compatible with BIM software, such as Revit Architecture, to perform comprehensive preliminary building energy performance analysis. It combines an intuitive 3-D design interface with a comprehensive set of performance analysis functions and interactive information displays (Marsh 2003; Crawley et al. 2008). These functions cover thermal, energy, lighting, shading, acoustics, cost and environmental aspects (Crawley et al. 2008). Since the operation stage is usually significant in energy consumption and CO_2 emission (Junnila and Horvath 2003; Zabalza Bribián et al. 2009; Kofoworola and Gheewala 2008), in order to ensure the accuracy of the result, Ecotect was used to simulate the heating and cooling load in the operation stage of the building under its defined geometry, material properties and local weather conditions.

Alternative design configurations: Life cycle performance (in terms of CO_2 emission and energy consumption) comparisons of different designs were performed based on several alternative designs. Table 2 contains the alternative design configurations with the original design as the baseline.

Life Cycle Analysis of the Building

Fig. 2 shows the life cycle of the building, for each stage, three main operations have to be performed. First, inventory items were listed, and then different methods were adopted to collect data for inventory quantification. Finally, based on these numbers, CO_2 emission and energy consumption were accumulated.

Table 2

Alternative design configurations

Design ID	**Changes to original design**
D0	Baseline design
D1	Change of Insulations 1) Exterior Walls changed from R19 to R30; 2) Roof changed from R24 to R36; 3) Basement Walls changed from R11 to R19.
D2	Replace glass curtain wall with brick wall
D3	Change orientations
D4	Change indoor temperature set from 18°C-26°C to 17°C-27°C

Raw Materials and Manufacturing Stage

The mass considered here only included the initial mass of installed materials. The Finnish building classification system (Kiiras and Tiula 1999; Junnila and Horvath 2003) was adopted as a basis to group the materials, products consumed in the building. The following building components: foundation, structural frame, envelope, internal components, as well as service system were included. Based on the original drawings of the building and Standard Construction Estimation Report, the quantity of the major materials and products was estimated. Parameters from the BEDEC database (CICT 2009) which was cited in Zabalza Bribián et al. (2009) ,were used to perform calculations because it contained the embodied energy and CO_2 emissions associated with the building materials, considering raw materials supply, transport and manufacturing (Zabalza Bribián et al. 2009).

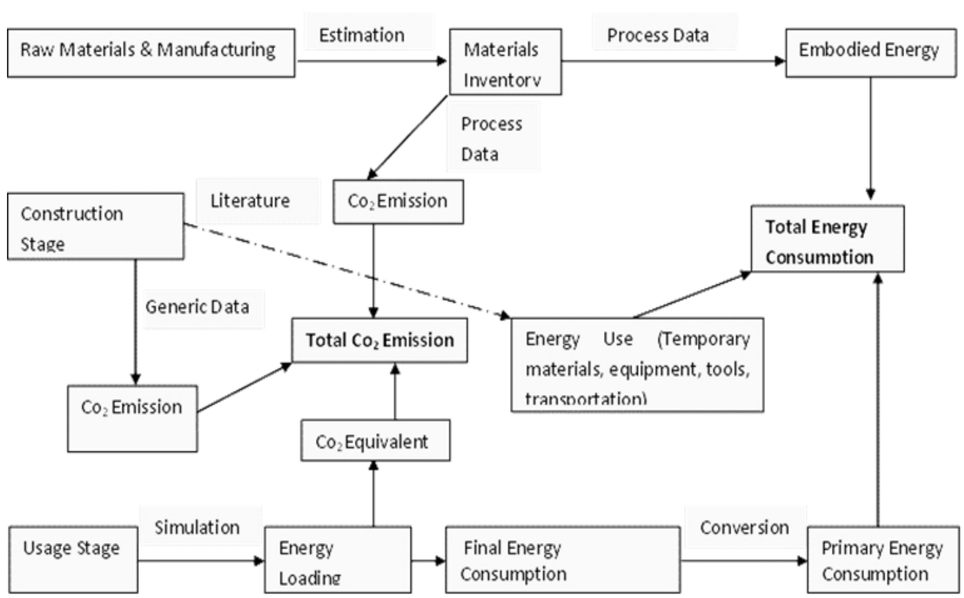


Figure 2: LCA framework used in this study

Construction Stage

The construction stage was limited by transportation from the manufactures', suppliers' and to waste handlers' gates and included transportation of materials and equipment to and from the building site, onsite construction activities, including site preparation, structural, envelope, mechanical,electrical equipment installation, and interior finishing, equipment use, and construction services (Guggemos and Horvath 2005; Bilec et al. 2010;). For the calculation of the energy consumption in the construction stage, an average amount of 418 MJ/m^2 obtained from Guggemos and Horvath (2005) was used because the case study in Guggemos and Horvath (2005) was also a steel framed structure

(Scheuer et al. 2003; Bilec et al. 2010). The software *BuildCarbonNeutral* was used to calculate the CO_2 emitted during the construction stage (Build Carbon Neutral 2010). For the following scenarios comparison, the amount of the energy consumption and CO_2 emission in this stage was kept the same.

Operation Stage

Operation stage activities consisted of energy consumption required for space heating, and cooling in winter and summer respectively. BIM model containing material properties and thermal space definition was imported into Ecotect where local weather data was loaded and energy simulation was done for different design conditions. Ecotect used CIBSE Admittance method to simulate the cooling and heating load (Rees and Spitler 2000). This load was converted to the amount of the electricity consumption and then to the primary energy consumption. The conversion factor for final energy to primary energy is 3.2 (Zabalza Bribián et al. 2009).

Results

Based on the method described above, calculations of energy consumption and CO_2 emission for all included life cycle stages were performed. Lifecycle energy consumption and CO_2 emission were computed by summing energy consumption and CO_2 emission in separate life stages, respectively (Eq. 1 and Eq. 2). Results of different objectives preset were presented in this section.

$$\text{Energy}_{LC} = \sum_{i=1}^{3} E_i \qquad (1)$$

$$CO_{2\,LC} = \sum_{i=1}^{3} CO_{2i} \qquad (2)$$

Where Energy $_{LC}$ is life cycle energy consumption; E_i is energy consumption in the *i*th stage; CO_{2LC} is total life cycle CO_2 emission; and CO_{2i} is the CO_2 emission in the *i*th stage.

Embodied Energy and CO_2 Emission in D0

Analysis indicated that steel, mortar and glass are the most significant materials (products) in terms of their embodied energy, which accounted for about 62%, 15%, and 12%, respectively, of the total embodied energy from materials utilized in the building (Fig. 3). In the comparison of CO_2 emission of different materials (products), steel, mortar and glass are also the top three significant contributors to CO_2 emission, giving off about 54%, 20%, and 10%, respectively, of the total CO_2 emission in the Raw Materials and Manufacturing stage (Fig. 4). The dominance of these three materials in both embodied energy and CO_2 emission could be attributed to either their large quantities supplied for the building construction or their great unit contribution.

Life Cycle Energy Consumption and CO_2 Emission of D0

Life Cycle Energy Consumption

Fig. 5 shows the distribution of energy consumption in different life cycle stages. The results revealed that operation stage activities consumed most energy, accounting for nearly 92% of total energy consumption during the life cycle of the building, followed by the embodied energy, approximately 8% of total life cycle energy consumption. From the analysis results, construction stage consumed the least energy. Compared to other stages considered in this study the energy consumptions in construction stage are negligible.

The fifty-year life time was used for lifecycle energy consumption calculation. If thirty years were used for the building's life expectancy the proportion of the energy consumption of operation stage will be less dominant. Some studies used the ratio of embodied energy to annual primary energy demand to characterize buildings' energy features. Its unit is year. For example, a ratio of 4 means the embodied energy is equivalent to the energy consumed by the building in 4 years (Scheuer et al. 2003). For the studied building, the ratio is about 4.2, which means after 4.2 years the operation energy demand will exceed the embodied energy. Compared to the above results reported, it seems this building has greater operation energy efficiency.

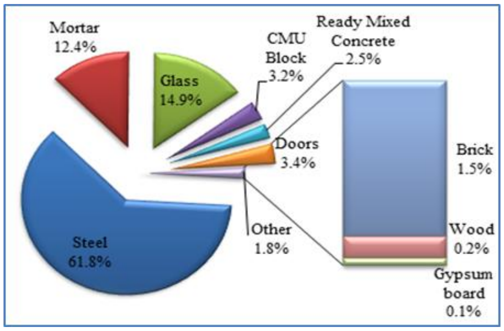


Figure 3: Embodied energy distribution (D0)

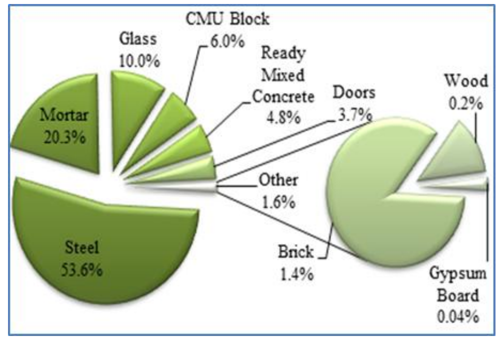


Figure 4: CO2 emission distribution (D0)

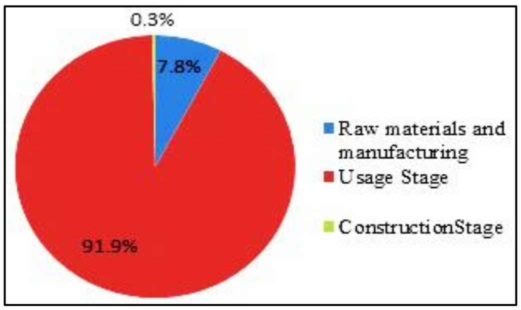


Figure 5: Life cycle energy distribution (D0)

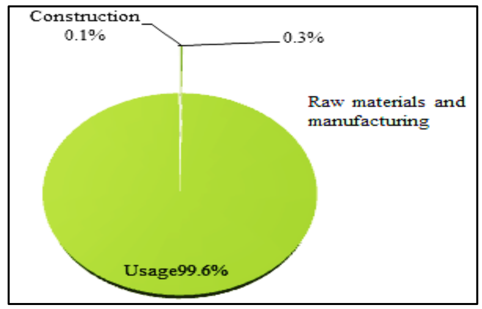


Figure 6: Life cycle CO2 emission distribution (D0)

Life Cycle CO2 Emission

Fig. 6 presents the distribution of CO_2 emission among different stages. From the distribution, the similar order, in terms of the contribution to total CO_2 emission of different stages, was shown as the contribution order of different stages to total energy consumption. However, it showed more difference between operation stages and other stages. More than 99% of the total life cycle CO_2 emission was induced by operation of the building.
In the research of Seo and Hwang (2001), different percentages of CO_2 emissions resulting from operation were found for different types of architectures, 88–96% for a single-family house, 95–97% for an apartment, and 93–96% for a multifamily house, respectively. The result from this study is somewhat higher than the reported results, which could result from the different source of energy that is used or different occupancy factors such as the level of insulation and the efficiency of appliances (Seo and Hwang 2001).

Implications of Building Design Changes

Life Cycle Energy Consumption Variation in Different Designs

As is shown in Table 2, different changes have been made to create different imagined designs and to check life cycle energy consumption and CO_2 emission variation among the chosen designs. The R-value measures the insulation's resistance to heat flow (DOE 2010b). The higher R-value represents better insulation performance. In D1, R-values of exterior walls, roof, and basement walls in this building were increased to new values. In D2, curtain walls in original design were replaced by brick walls for top three floors. D3 was produced by rotating the original building in clockwise direction by 180°.In D4, indoor temperature set was extended from comfort zone (18 °C-26 °C) to the temperature range 17°C-27°C.

Fig. 7 shows energy consumption comparison between different designs. In terms of life cycle energy consumption, the sequence of the amount is D0>D3>D1>D4>D2. Compared to the original design, D3 and D1 reduced energy consumption slightly. D2 saved the most energy, which meant replacing curtain walls in original design with brick walls for top three floors is more effective in reducing energy consumption than increasing R-values (D1), rotating the original building in clockwise direction by 180° (D3) or extending the indoor temperature range (D4).

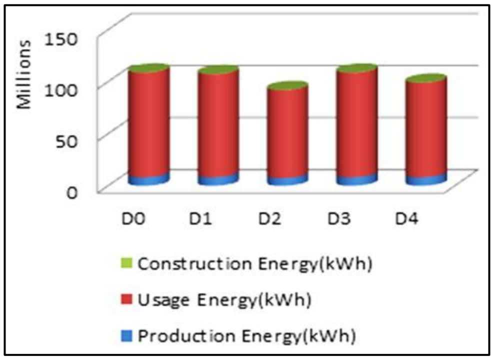
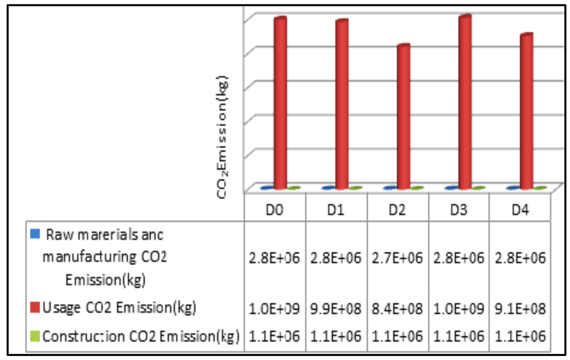


Figure 7: Energy consumption comparison



	D0	D1	D2	D3	D4
Raw marerials anc manufacturing CO2 Emission(kg)	2.8E+06	2.8E+06	2.7E+06	2.8E+06	2.8E+06
Usage CO2 Emission(kg)	1.0E+09	9.9E+08	8.4E+08	1.0E+09	9.1E+08
Construction CO2 Emission(kg)	1.1E+06	1.1E+06	1.1E+06	1.1E+06	1.1E+06

Figure 8: CO_2 emission comparison

CO_2 Emission Variation in Different Designs

In terms of the amount of life cycle CO_2 emission, the sequence is similar to the sequence in life cycle energy consumption (D0>D3>D1>D4>D2) (Fig. 8).The CO_2 emission amounts in D0 and D3 were approximately equal. Compared to the original design, CO_2 emission of D1 was decreased little. D2 generated the least amount CO_2 emission, which meant replacing curtain walls by brick walls for top three floors is most effective among all designs.

Sensitivity Analysis

In order to further investigate the relationship between building performance and its influence factors, sensitivity analysis was performed.

As shown in the above analysis, operation stage is dominant in both life cycle energy consumption (about 92%) and life cycle CO_2 emission (>99%). Annual energy consumption in operation stage was chosen as the sole parameter to test the efficiency of different factors.

Several factors that affect the annual operation energy consumption were chosen for sensitivity analysis, including 1) Indoor temperature set; 2) wall type; 3) R-values for exterior wall, roof, basement wall; and 4) orientation. Fig. 9 displays the sensitivity analysis of annual energy consumption on the factors including indoor temperature set and wall type and R-values. It revealed that the two most sensitive factors for yearly energy consumption of the building are “temperature change” and “curtain wall replacement”. However, in this study, two relationship lines varied. One is positive while the other one is negative. The sensitivity of the annual energy consumption of the building to other factors (except orientation) are weaker, nearly zero.

Orientation change is difficult to be expressed in percentage change. In this study, the relationship between the annual energy consumption variation and orientation of the building change was described in the spider graph (Fig.10). It revealed that when the building was rotated by 180°, either clockwise or counterclockwise direction, the annual energy consumption changed the most, increased by about 2%. If the building was counterclockwise and clockwise turned around by 90°, the annual energy consumption of the building could decrease 0.78%, 0.39%, respectively.

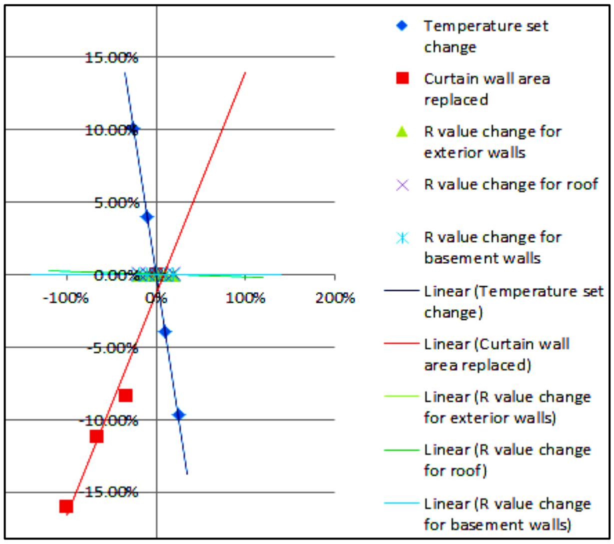


Figure 9: The sensitivity of annual energy consumption to different factors

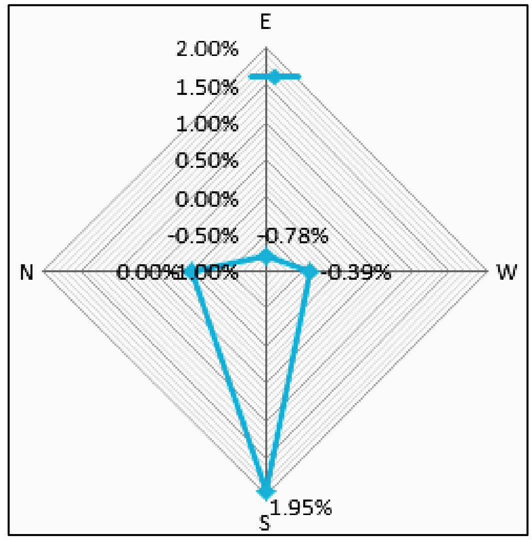


Figure 10: Annual energy consumption change with different orientations

Conclusion

From this case study, it can be concluded that BIM and Ecotect can be very helpful in performing LCA, since they can provide majority of the necessary information and calculation tools for performing LCA, which may alleviate the difficulty that, when executing building LCA, there is not enough available information. This difficulty has deferred the extensive utilization of LCA technique in the building/construction sector.

Life cycle energy consumption comparison showed the operation stage is the biggest contributor to energy consumption. More than 90% of the total energy was used during operation. The embodied energy in raw materials and manufacturing stage only accounted for 7.8% of the total energy. The construction stage consumed less percentage (<1%) of the total energy. Steel products owned the most energy, more than 60% of the total embodied energy for all materials, due to large amount of steel used in this building. It showed the same order of three stages for the CO_2 emission. For raw building materials and manufacturing stage, the order of materials utilized in this building in term of CO_2 emission was similar to the order in terms of embodied energy. The only difference lied in the order of ready-mixed concrete and doors.

Different effects were produced as designs changed. Some actions, like replacing curtain wall by brick walls for top three floors and changing indoor temperature, were more effective in reducing energy consumption and CO_2 emission than others. From the process of sensitivity analysis, based on the linear relationship assumptions, the annually consumed operation energy is more sensitive to the curtain wall area change and indoor temperature change among the chosen factors except the change of building orientation. However, these two changes produced contrary effects on annual energy consumption for using the building.

Although it is difficult to quantify the sensitivity degree between annual operation energy consumption reduction and building orientation change, it really showed that the orientation of the building could affect the annual operation energy consumption. Different rotation directions may lead to different environmental effects.

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