Application of BIM in Building HVAC Energy Consumption Analysis

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Abstract:

Building information modelling (BIM) is an evolving technology in which design process is supported by various software that allows developers, businesses and government bodies to plan, design and construct new buildings in a common data environment with its consultants and contractors (Bernstein et al., 2010). BIM is arguably a catalytic agent in enhancing building energy efficiency and effectiveness, meanwhile diminishing the excessive energy costs from inadequate design in the construction industry (Succar, 2009).

This study aims to review the functions and development of BIM Technology by applying BIM technology in HVAC energy consumption analysis with different combinations of building environmental factor and evaluating the effectiveness of BIM in building energy consumption simulation. Two tests have been conducted for achieving the research aims. Test 1 would be discovering the effect of WWR in 4 directions of building on HVAC energy consumption in terms of **kWh/m2/year on Autodesk Insight.** Test 2 would be the effects of thermal properties of walls and glazing of windows on HVAC energy consumption in terms of **kW on Revit**. Process of conducting these two tests would be recorded for evaluating the effectiveness in adopting BIM in building HVAC energy simulation. Benefits, barriers and recommendations in implementing BIM for building energy analysis would also be concluded.

Keywords:

Building Information Modelling, Building Energy Analysis, Revit, Building Energy Consumption, HVAC system

Introduction:

Building information modelling (BIM) is an evolving technology in which design process is supported by various software that allows developers, businesses and government bodies to plan, design and construct new buildings in a common data environment with its consultants and contractors (Bernstein et al., 2010). BIM is arguably a catalytic agent in enhancing building energy efficiency and effectiveness, meanwhile diminishing the excessive energy costs from inadequate design in the construction industry (Succar, 2009). During the design stages, building project consultants use BIM for visualising the building design by constructing a building model on BIM modelling software. With this building model, they could undergo building energy consumption analysis of the building MEP system design by the MEP consultants. Consultants could adjust their designs to enhance the energy efficiency of the building further and meet developers' expectation in minimising energy consumption.

Building energy consumption has become a critical design consideration for building design in modern projects as decisions made in the early design stages have a significant effect on growing awareness of minimising building energy consumption (Basbagill et al., 2013). During the design stage, BIM makes multi-disciplinary data exchange available which is then to be incorporated on one single building model that enables possibility in visualising and analysing the building project in term of a building model. Building energy analysis is available with the aid of different BIM toolkits and applications, such as eQuest and EnergyPlus, Autodesk Insight and Autodesk CFD. Architects and building engineers could utilise these toolkits and applications in simulating the building's energy consumption with the building data provided during the data exchange for design decision related to building energy and even building sustainability. Hiyama et al. (2014) also suggested that results obtained from these simulations from BIM could assist building designers in adjusting the existing configurations of building parameters for optimising the optimal building energy performance during the design phases of a building project.

In this research, the suitability of adopting BIM technology for building energy consumption analysis in minimising building energy use would be explored. The building energy analysis conducted would be wholly focused on the HVAC system on cooling load because the HVAC system is by far the most significant energy end-use in buildings of Hong Kong (EMSD, 2019). This research is intented to discover if BIM could help to determine the best building design to reduce HVAC energy consumption.

To fill up the above research gap, the research aims:

(i) To review the functions and development of BIM Technology,
(ii) To apply BIM technology in HVAC energy consumption analysis with different combinations of building environmental factors and
(iii) To evaluate the effectiveness of BIM in building energy consumption simulation

In recent years, there is a huge evolvement in BIM technology. Different software developers have launched new toolkits for the technological advancement of BIM. In this study, an HVAC energy analysis based on an existing public housing building is conducted on the base of information exchange.

Literature Review

1.1 Studies related to estimating building energy consumption by using BIM

The current trends in energy use around the globe have raised serious issues over the exhaustion of energy sources, and severe impacts on the environment (Li and Yao, 2009). According to the outlook from IEA (2019), developing regions such as China and India increased by five times when comparing today's energy consumption with their original data in 1971. The outlook indicates that energy demands will continue to soar in the future due to climate changes and global warming. The above data may seem to be beyond the scope of the research, but urbanisation, globalisation and enhancement of living quality in developing regions would be more common in the future, and

more people would be living in buildings as suggested in Li and Yao (2009) journal and increase the demand in energy to cater to the consumption that would create serious environmental impacts.

BIM would play a crucial role in future building projects, including estimating building energy consumption under the current trend of integrated project delivery and design optimisation. As buildings would become the most common places for living in the urban area, measures that assist in minimising energy consumption in future buildings would be the key to limiting energy use and achieve sustainability. Building performance analysis represents a series of assessments and evaluations determining the environmental performance of the building during the conceptual design stage, which includes solar and thermal energy, ventilation, daylighting, site orientation together with HVAC systems optimization (GSA, 2009). Building performance analysis represents a series of assessments and evaluations determining the environmental performance of the building during the conceptual design stage. It simulates the actual energy usage and cost during the building's lifespan for stimulating building design improvements by building designers and engineers (Yuan and Yuan, 2011). They are enabled to make energy-conscious design decisions according to the simulated results which facilitate early detection and diagnose energy-deficient defects.

During the early design stages, a simple building energy model is constructed which will provide a glimpse of the building's energy performance (Wong and Fan, 2013). The energy model would be a database of the new building, providing information such as details of HVAC system, building use, spaces and the occupancy level, which can be used to simulate building performance and energy consumption. Wong & Fan (2013) had further concluded some of the advantages in adopting BIM in estimating building energy consumption. They include:

- Able to select the most optimal building orientation for the best building energy efficiency
- Able to analyse and optimise the building's form and envelope
- Able to conduct daylighting analysis
- Able to analyse and evaluate different system options to reduce energy consumption
- Able to analyse and evaluate different building materials to reduce energy consumption

Considering the benefit brought from BIM technology in building energy consumption analysis, it is still not widely adopted in Hong Kong at present. From the latest research on BIM technology adoption conducted by CIC in 2019, more than half of the BIM adopters consider BIM technology as beneficial in improving planning and analysis. However, only 33% and 31% of the BIM adopters in Hong Kong are using BIM for analysis, including building energy analysis. BIM could play in a more important role in the local's construction industry given the advantages brought by BIM in estimating building energy consumption

1.2 Situation of energy consumption due to air-conditioning systems in buildings

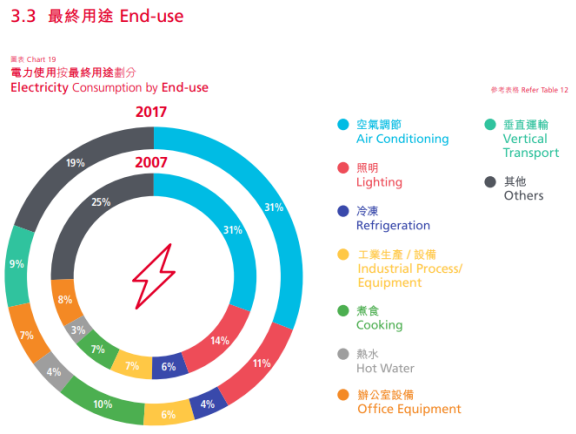

Figure 1. Distribution of Electricity End-use in Hong Kong (source: EMSD, 2019)

Air conditioning accounted for nearly one third of total energy end-use in Hong Kong last year. In 2019, 31% of overall electricity end-use in Hong Kong were consumed by air-conditioning (EMSD, 2019). In the residential sector, the percentage of air conditioning was 27% and it was 25% in the commercial sector. There was also an rising upward trend in Hong Kong over the last 10 years in the energy consumption of air conditioning at different types of building.

In addition, recent research on the energy end-use of air conditioning conducted by *International Energy Agency* also revealed the recent energy usage of air conditioning across the globe and the growing demand for air conditioning in the coming years. IEA (2018) discovered the total electricity used in building by air conditioning is approximately 20% in the world. The demand for air conditioning was and will be soaring and become the main driver in the increasing energy demand from the building sector in the coming decades. IEA suggested more efficient air conditioning units should be adopted in order to reduce the need of new power plants to accommodate the extra electricity demand, control the rise in operation cost and CO_2 emission in the future. With the increased demand in air conditioning, building designers and engineers should implement measures and adopt energy saving strategies during the design stages in minimising the energy use of air conditioning for sustainability.

1.3 Estimating the HVAC energy consumption by using Revit

The Autodesk Revit provides built-in heating and cooling loads calculation tool with reference to the spaces and zones created in the building energy model (Autodesk, 2019). The building material properties and building location data are also considered in the heating and cooling loads calculation in order to provide an accurate HVAC energy consumption. It also allows export of gbXML file, which contains all heating and cooling information, for the further design process and energy analysis in other analysis software.

The Autodesk Insight is a plug-in energy analysis toolkit on top of the Autodesk Revit (Egger, 2015). It complements the existing built-in energy analysis function in Revit and provides a more interactive user experience to the building engineers and designers. It aims to visualise the building model according to building spaces and zones. Reports are generated with automatic analytical model creation using the model constructed in the Revit modelling software. It could visualise performance information directly in the modelling environment, interact with and select the relevant building data for analysis from the building information model, such as doors, windows, walls, building's geometry, geographic information, etc. More business-related indicators such as KPIs, benchmarks, factors, ranges and specifications with feedback from real time design option adjustments would allow engineers to enhance the building energy efficiency.

During the analysis, simulation engines from Autodesk would conduct simulations on whole building energy consumption, HVAC, daylighting and solar radiation using cloud computing services and display all potential outcomes after the simulation. Results from Autodesk Insight is shareable between different stakeholders in the building project and it is accessible 24/7 anywhere to facilitate early design adjustments and feasibility studies throughout the design stages of the project.

Methodology

A building model would be developed on Autodesk Revit based on an existing local public housing building for data collection and evaluation of BIM technology in building modelling. The building floor plan is available on Housing Authority's website. The selected building type is "**Standard Block New Slab (Single Wing)**" which could be found in Tsui Ping (North) Estate as it is one of the most common public housing designs in Hong Kong. VRF system would be chosen as the HVAC system in the building model. The building model developed on Autodesk Revit would undergo energy analysis with varied combinations of building parameters, such as thermal transmittance of exterior wall and solar radiation absorptance of windows, on the HVAC system. Further HVAC energy analysis on WWR would be conducted in Autodesk Insight. Data obtained from these energy simulations are essential to find the most effective factor in improving energy consumption and evaluate the effectiveness of BIM technology in building energy analysis. Analysis procedures are as below:

Test 1 - In Autodesk Insight

1. Obtain simulated energy consumption results from the initial **(assumed)** building model in **Autodesk Insight.**
2. Check WWR sections for obtaining changes in HVAC energy consumption with different WWR settings on four orientations.

Test 2 – In Autodesk Revit

1. Obtain simulated energy consumption results from the initial **(assumed)** building model in **Revit.**
2. Adjust building parameters such as thermal transmittance of exterior wall and solar radiation absorptance of windows to discover the change in HVAC energy consumption.

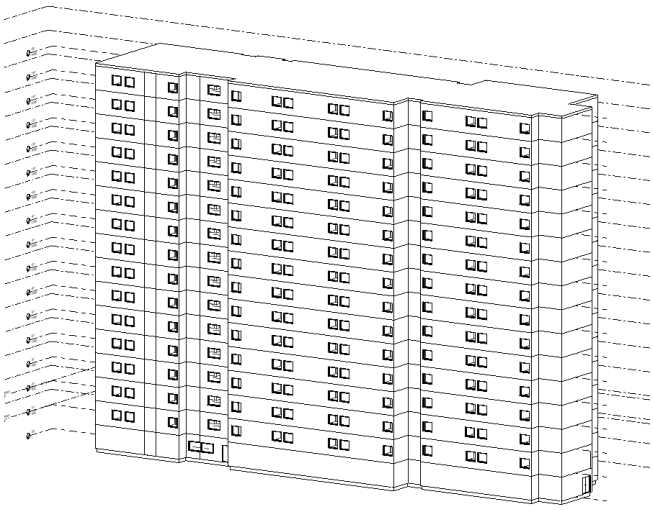

Figure 2. Building Model in Revit

Results

Test 1

After configuring the building model for energy analysis, the analysed result is generated on Autodesk Insight website. Different measures in minimising building energy consumption are listed for building engineers' further adjustments. The total HVAC energy consumption for the building is **51.8 kWh/m^2/yr (190520 kWh/year)**. Measures to further reducing HVAC energy consumption are shown in the palettes below.

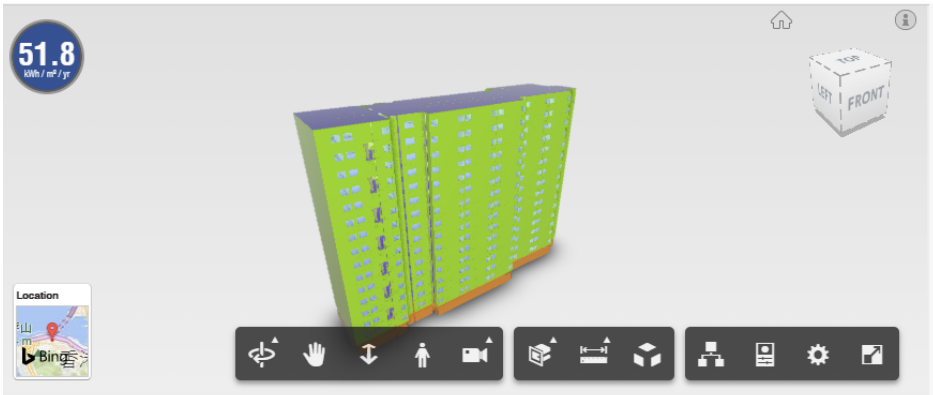

Figure 3. Energy Model on Autodesk Insight

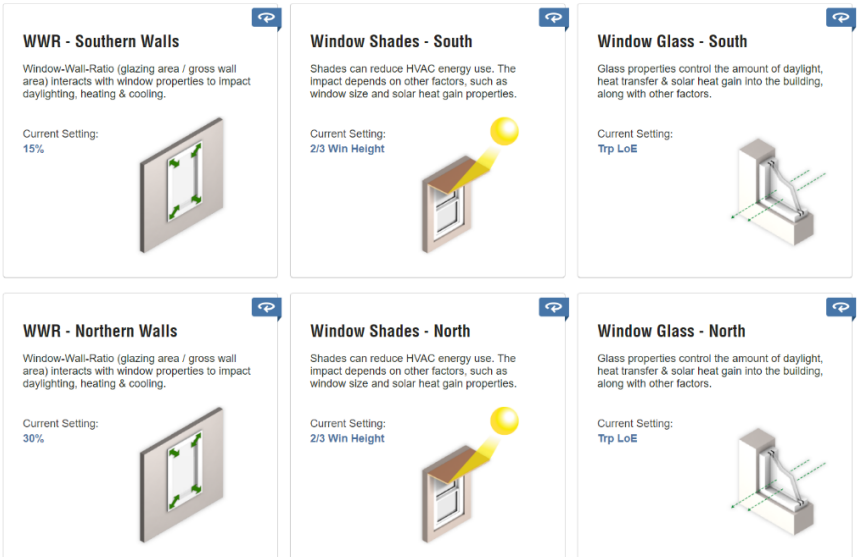

Figure 4. Palettes in Autodesk Insight indicating possible energy reduction measures

Table below summarised the analysed potential HVAC energy saving by adjusting WWR on the four orientations of the building model.

Façade(s)	**Potential HVAC Energy Saving (kWh/year)**
North	1655
South	2537
East	0
West	0

The analysed result indicated that there would be a **2537 kWh/year** potential HVAC energy saving by adjusting the WWR on the south façade. The following deductions could be made according to the data obtained from the analysis.

1. Reducing WWR of any façade of a building could assist in lowering HVAC energy saving.
2. Reducing WWR of façade that mostly under sunlight could have a more significant effect in reducing HVAC energy consumption in a year. South façade is simulated as the façade that receives most sunlight all year round. By reducing the WWR at south façade, the energy reduction effect on HVAC is the most significant among the other façades.

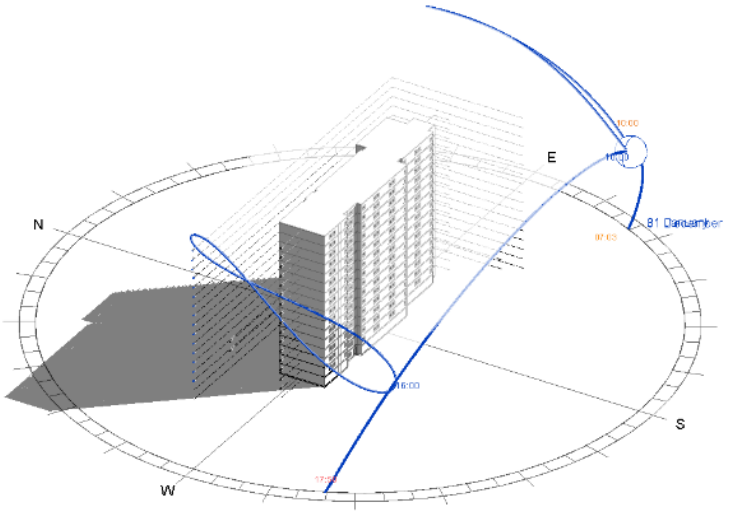

Figure 5. Sun path of the Building Model

Test 2

In this part, the relationship between building parameters and HVAC energy consumption would be studied using Autodesk Revit cooling load calculation tool. The building parameters include exterior walls, thermal transmittance, and window glazing. The building parameters would be varied and cooling load calculation would be conducted accordingly to indicate the change in building cooling load. The HVAC energy consumption would be represented by peak cooling load in terms of kW and the most effective factors in enhancing HVAC energy consumption would be distinguished after the analysis. The total cooling load of the initial (assumed) building model is **550 kW**. The table below summarised the analysed potential HVAC energy saving by adjusting thermal transmittance of exterior walls and solar absorptance of window glazing of the building model.

Thermal Transmittance of Exterior Walls

Insulation Thickness (mm)	**Cooling Load (kW)**	**Percentage Decrease from the Former Data (%)**
0	550	/
25	452	17.8
50	422	6.63
75	406	3.8
100	382	5.9

Solar Absorptance of Window Glazing

SHGC	**Cooling Load (kW)**	**Percentage Decrease from the Former Data (%)**
0.7	550	/
0.6	529	3.82
0.5	505	4.54
0.4	486	3.76
0.3	469	3.5

The above data indicates the effect of thermal transmittance on HVAC energy consumption is relatively more significant than the effect of solar absorptance of window glazing on HVAC energy consumption. Building engineers and designers should consider increasing the thermal insulation of exterior walls to minimise HVAC energy consumption.

Conclusion

1.1 Benefits of Utilising BIM in Analysing Building Energy

With the results obtained from test 1 and 2 in chapter 4 and the modelling process before the tests, the following benefits of implementing BIM technology in building energy analysis are concluded as follows:

Seamless Building Drawings Importing and Building Modelling

Revit allows end users to import *.dwg* format drawing files from AutoCAD to Revit for building modelling. AutoCAD is one of the most widely used CAD software on the market at present and using software products under Autodesk could have seamless drawing import from AutoCAD to Revit. Engineers could follow the drawings and develop a building model for energy analysis later. Different building parameters such as WWR, thermal Transmittance and solar radiation absorptance of external walls could be configured and selected during the modelling process.

Straightforward Building Energy Analysis

With the building model constructed, building space indicated in Revit, Insight could undergo building energy analysis accordingly. Engineers could enter site location data and select the preferred HVAC systems and other site properties before simulating building energy consumption. A detailed cooling load calculation is then provided on Revit after the analysis with a clear breakdown of the cooling figure in each designated building space. Engineers could adjust system configuration and building parameters according to the data provided.

Provide Suggestions for Different Design Strategies and Solution

A suggested energy strategy and solution are further provided in the report in Autodesk Insight to facilitate further design adjustments from the engineers. Insight would compare different design options and visualise the proposed energy options and its energy consumption for engineer's considerations. Data collection process by different combinations of building environmental factors in Insight could simulate a real-world situation as Insight has its machine learning process. It would show limitations and shortcomings of different building design measures and assist engineers in making the appropriate adjustments to the building systems.

1.2 Barriers of Utilising BIM in Analysing Building Energy

Incompetence in BIM software for exploring energy consumption with a different set of parameters

As mentioned in previous sections, Revit does allow end users to adjust different building parameters while building energy consumption, but it only allows users to adjust either the conceptual type of parameters for the whole building or use Revit's built-in building parameters or properties without much customisation for end users. End users must create their own building materials on Revit for every wall which would greatly diminish the efficiency of energy analysis on Revit. Besides, Revit has failed to consider *Rin* and *Rout* for building HVAC energy analysis. Software such as eQuest and EnergyPlus allow end users to freely adjust building parameters as sophisticated as *Rin, Rout* for energy consumption analysis. Other BIM software could provide a more accurate HVAC energy analysis results than Autodesk Revit. It indicates that the standards of different BIM software could be unevenly matched. Building engineers must be well-aware of this issue in order to obtain an accurate building energy analysis result.

Absence of Localisation in BIM Software

As major BIM software developers are based in the United States or Europe, major components of different BIM software are mainly based on their local industry practice, data, regulation and requirements. During the analysis in Autodesk Insight, energy saving potential is calculated as either USD/m2/year or CNY/m2/year without the choice of HKD/m2/year considering Hong Kong is a relatively smaller building industry than Mainland China. Also, cooling load visualisation is not available due to the unsupported site location (Hong Kong). Software developers shall consider supporting more market in order to allow the building industry around the globe to share the advantages brought by BIM technology.

1.3 Suitability of Implementing BIM in Building Energy Analysis

With the research results and the summaries of benefits and barriers of BIM technology implementation above, it is concluded that BIM technology is suitable in determining the best building design to reduce building energy consumption.

It is found that BIM technology is mature for building energy analysis as there are an array of BIM toolkits that are available for building energy analysis. The workflow of building energy analysis is to some extend convenient in building designers' perspective with different energy analysis could be conducted by different building

parameters and properties. The building energy modelling process is simple on Autodesk Revit, which allows *.dwg* files to be imported into Autodesk Revit as the base for constructing the building energy model.

There is also an interactive energy analysis result on Autodesk Insight with interactive graphs showing the potential energy saving at the building. Insight has consolidated the energy saving measures by calculating the potential energy saving in building energy cost per year. Building engineers could consider the energy saving measures as suggested in Insight to reduce the energy consumption in the building further.

However, it is in the early stages of implementing BIM technology in Hong Kong's construction industry that of 56% local building industry firms identified as 'BIM Laggers' (CIC, 2019). It is discovered that BIM software developers do not take the initiative in localising their software to cater to local needs. For instance, Autodesk Insight failed to generate cooling load visualisation when site location is set to be Hong Kong. The localisation of BIM software could possibly be seen if more building projects in Hong Kong adopt BIM technology during the design stages.

Based on the findings in the previous part of this research, the potential of BIM technology in building energy analysis is apparent with related technologies evolving year after year. It is suitable to implement BIM in Building Energy Analysis. However, local industry support would be a crucial factor in the localisation of BIM software.

1.4 Recommendation for Future Work

This research has demonstrated the workflow of building HVAC energy analysis by changing different building parameters on different BIM toolkits and software. However, this research only considers the implementation of BIM technology in between building owners' and designers' perspectives without attempting to implement BIM in a project team's and contractors' perspectives. Below are some recommendations for future work towards the cooperation of different parties within a building project with the aid of BIM technology on building HVAC energy consumption.

Data Transfer between Different Parties

In this project, the building energy model is created and immediately underwent building HVAC energy consumption analysis in the same software. In the real project situation, building energy model could possibly be created by a BIM consultant and shared to the energy consultant for building energy analysis. Future works could be conducted to discover the interoperability of different BIM software and files for further assessment on the suitability of applying BIM in building energy analysis.

Customising Building Models to Cater to Project Needs

The building energy analysis is necessary for a project, the building energy model should make a balance between the model complication and the parameters requirement. The model should include all the necessary building parameters for energy analysis and avoid excessive data that may affect the accuracy of the energy analysis along the design process.

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