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An Inquisition of Envelope Fabric for Building Energy Performance Using Prominent BIM-BPS Tools—A Case Study in Sub-Tropical Climate

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Abstract. Energy efficient building is enhancing a worldwide movement as a policy to lessen the carbon footprint. With the intention of zero energy building in sub-tropical climates, exertion should be placed to minimize the overall energy usage to the greatest scope by incorporating apposite construction skills into the whole design process. Suitable building envelope resources is one of the most effective ways to manage energy flows, minimize energy loss, and maintain a comfortable environment for occupants. In the present paper, a conventional building (Educational) in Hong Kong is considered and the goal is to identify and prioritize the potential energy saving opportunities through the implications of multiple envelopes (walls, windows, etc.) fabric using dynamic BIM-BPS process for potential retrofitting. A conceptual framework is proposed for comprehensive energy assessment using BIM (e.g. Revit 2019) and BPS tools (e.g. e-QUEST) to simulate the energy performance of the building. Using a calibrated model, several high performances envelop fabric are considered to perform a parametric investigation (e.g. walls, windows) through active simulation process. In order to achieve more realistic conditioning, an assumed occupancy profile also considered during the energy analysis. Results have shown that a significant saving of 11.45% in yearly entailed total building energy. The study can help with the decision-making analysis regarding future retrofitting opportunities in a sub-tropical climate.

1. Introduction

The building industry is one in every of the largest users of energy and CO₂ emitters within the world. UNEP appealed that the constructing zone denotes about 40% of world electricity usage and produces about 30% of the greenhouse gas emanations [1]. In the meantime, the building creation events also consume environmental belongings and convey a huge quantity of waste and energy [2, 3, 4, 5]. Through this historical past, the idea of green or energy efficient building has been planned and endorsed widely which obtains sustainable improvement in the constructing zone [6, 7, 8]. As said by the IPCC (Intergovernmental Panel on Climate Change) AR5 (Fifth Assessment Report) report, worldwide constructions have been accountable for around 32% of energy and harmful emission around 19% of energy-associated adverse gases in 2010 [5]. The above-mentioned shares effect destructively at the surroundings and civilizations through worldwide global warming. All the way through rising fears of worldwide global warming, it is not a wonder that the building sector is nowadays starting to deal with the want for green or sustainable housings [9, 10]. For that reason, quite a few efforts had been paid on



locating suitable techniques and actions to decrease energy consumptions and environmental impacts of the high rise building that may lead to sustainable construction [10].

Choosing environmentally most effective building products is an extremely good method to reinforce a home's energy performance. Whilst there's obviously an immediate want for brand new technology to improve the application of low-impact envelope materials, it's also proper that there are numerous technologies or systems, currently in use [11]. Countless have originated from an in advance inflow of sustainable housing involvement and development, precipitated by using the 1970s environmental movement program, after which advanced by way of the pressure for higher energy efficient homes. Their policy has been known as effective in spreading thoughts approximately great exercise to committed green promoters, builders and people looking for an alternate way of determining the material-selection method, only a limited such schemes are to be had that help the powerful and enormous use of nearby and used building materials (e.g. Envelope) in the design-selection making segment of a constructing [11]. While such varieties of energy efficient building design can be challenging, Building Information Modeling (BIM) and Building Performance Simulation (BPS) simplifies the system. Presently, BIM combined BPS tools (e.g. e-Quest, EngyPlus, etc.) have the choice to provide stakeholders with a hazard to research miscellaneous energy saving alternatives early within the design level, consequently escaping the time-consuming practice of re-getting access to complete constructing geometry and different vital supporting data to complete the energy analysis. Similarly, BIM incorporated energy assessments tools ought to have a sizeable contribution to choosing materials and additives with a lower effect on the overall aid's consumption of buildings. In most of the cases, these elements are selected thinking about most effective useful, financial and technical situations [12].

Beforehand there are very few studies assessed building energy optimization by means of considering the multiple parametric investigations for the building envelope (e.g. walls, windows, roof, etc.) using the dynamic BIM-BPS tools. The envelope fabric facilitates between the internal and external surroundings by establishing a blockade to light, heat, air and other negative impacts. So, it is essential to design an appropriate building envelope fabric to attain an uppermost performance [13]. At the same time as the energy and resources optimization of the building is engrossed on the assortment of and disparity in construction materials built on their belongings, optimization, and form is bothered about fluctuating building sizes and shapes. Prior research tells about the most popular double skin façades implement two layers of covering to expand the envelope performance [13]. Notwithstanding these implications and enumerating, the influence of diverged building data on energy usage has not been wholly considered. This paper proposed a dynamic framework to investigate BIM-directed experimental simulation to compute the influence of building envelope (e.g. walls and windows) state on the total energy use. Thus, the research pursues to inaugurate the intensity to which connecting a BIM model with energy investigation software/tools such as Green Building Studio, e-Quest. These will help to deliver energy-efficient buildings and observe the long-standing improvement of the building's energy optimization in the hot-humid region.

2. Materials and Methods

2.1 Sub-tropical climate in Hong Kong

The latitude and longitude of case study location in Hong Kong are 22°18 N and 114°10 E respectively. This climate is considered as sub-tropical where mean temperature during winter month (November - February) is around 15-18°C. Several reports from Hong Kong Observatory revealed that it is usual for temperatures to drop less than 10 °C in urban areas, and the lowermost temperature reported is nearby 0°C. The spring term is pretty short, comprehend humid and occasionally very foggy environment. The temperature also has a tendency to vary widely from day to day. In the summer period, which comprises mid-April to September, the weather is mostly tropical, hot and humid with irregular thunderstorms and showers. Mid-day temperatures recurrently exceed 33°C between June and September, with an average temperature of around 28–30°C [14]. The autumn season also very short and continues in between

September and early November. The average annual rainfall in Hong Kong is around 2225 mm, approximately 80% of rain occurs between May and September. Due to the lengthy hot and humid summer period, a massive demand for air-conditioning for occupant comfort cooling. This is one of the greatest energy consumption sectors in this region. Numerous studies have been done about the building occupant comfort in sub-tropical climate in Hong Kong. The weather data in this study was derived from the Hong Kong Observatory (<https://www.hko.gov.hk>) and Department of Energy (DOE) website (<https://www.energy.gov.hk>).

2.2 Building occupancy profile

Evaluation of energy performance in superior buildings specifies that the actual outcomes of superior buildings are no longer as predicted or designed. Simulating building performance beneath practical circumstances which include human behaviour, is desirable in order to achieve further precise effects [15, 16, 17]. Inaccurate data related to people behaviour and building operation is a communal and great supply of error in building performance simulations (BPS) below genuine conditions [18,19]. Occupant's influence on building energy consumption is only regarded in the occupancy portion of energy simulation software (e.g. e-Quest). Input data related to occupancy in energy simulation software is restrained to occupants' presence in constant and scheduled patterns, and these do no longer replicate truth [16, 18]. Also, most specialists trust default occupancy lists of energy simulation tools for building performance analysis (BPS) [16, 19]. So, realizing the significance design team attempted to consider typical data on average occupancy schedule for this case study location shown in figure 1. The statistics can be entered into the simulation model at the occupancy profile section. This overall information to the simulation tools can be more suitable for the applicability of occupant behaviour modeling in real-life sketch initiatives as well. However, automation structures and sensing can play an important role in grasp the interaction with occupants by means of contributing particular data beneficial to unveil the dynamic operation patterns which are contributed to getting further precise results.

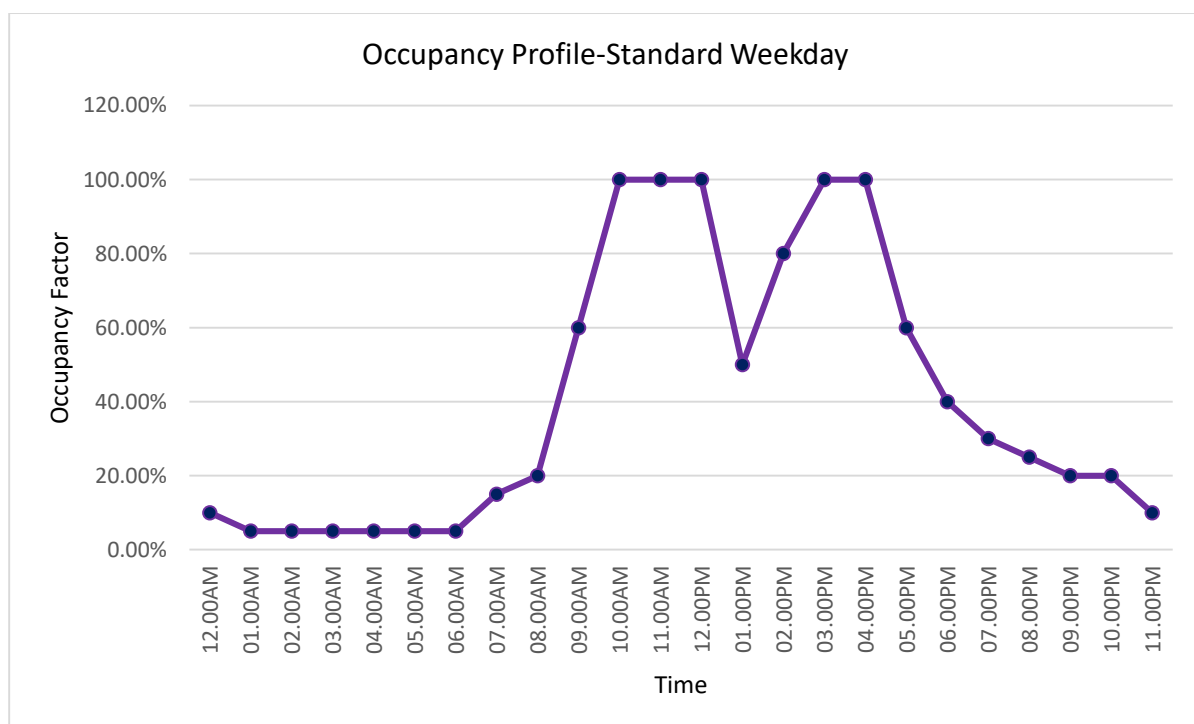


Figure 1. Assumed occupancy profile (Z-Block), The Hong Kong Polytechnic University

2.3 Building data

A 12-floor high-rise tower (Encompassing North and South tower) with a net floor area 25,600 m² is established as the baseline building in BIM to BPS (Building Performance Simulation) process. The building location is the northwest of the existing campus of Hong Kong Polytechnic University. The layout drawings, floor, materials information, and other possible data are mentioned in figure 2 and table 1. Additional data was gained through and discussions with experts, engineers, architects, as well as during site visits.

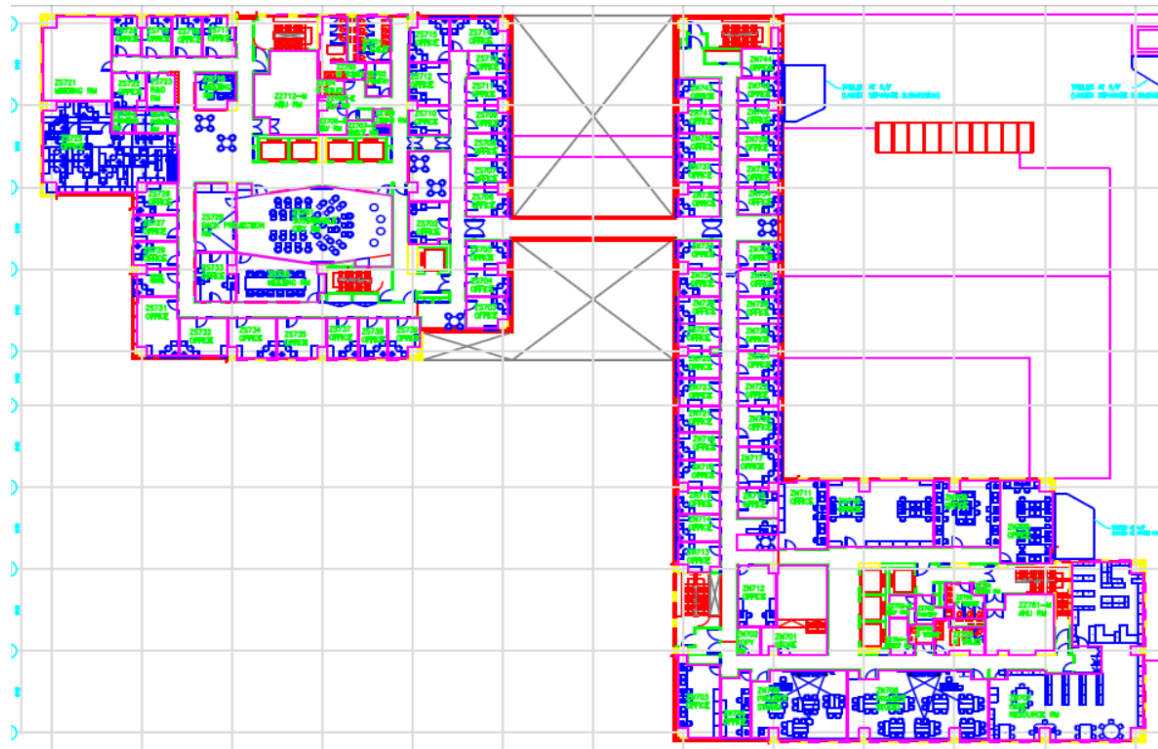


Figure 2. Floor Plan (7th Floor) for case study building

Table 1. Details of baseline building data

Element	Materials properties
Roof:	8 in heavyweight concrete with 2 in insulation and screeding ($U=0.3305$ W/(m ² K)), Density: 2400 Kg/m ³
External Wall:	8.5 in concrete wall ($U=1.99$ W/(m ² K)), Density: 2400 Kg/m ³ ,
Interior Wall:	8 in common brick ($U=1.8536$ W/(m ² K))
Ceiling:	6 in concrete ceiling ($U=3.4146$ W/(m ² K))
Doors:	Solid hardwood ($U=2.5572$ W/(m ² K))
Floor:	4 in heavyweight concrete floor deck ($U=3.8651$ W/(m ² K))
Exterior Windows:	Large single-glazed windows ($U=4.00$ W/(m ² K), SHGC=0.86), Density: 2500 Kg/m ³ , SC: 0.66
Skylights:	Large single-glazed Window ($U=6.7018$ W/(m ² K), SHGC=0.86)
HVAC	Central VAV, Electric Resistance Heat, Chiller 5.96 COP
LPD	1.35 W/m ²
Altitude	60'

Information of the selected buildings was gathered from the designated university authorities such as Facilities Management Office (FMO) and Campus Development Office (CDO) of The Hong Kong Polytechnic University.

2.4 Conceptual framework of modelling process

The proposed framework is used for the energy investigation of the case study building through the whole simulation process shown in figure 3. Firstly, model the case study building into the BIM tools (e.g. Revit 2019) and established more than thirty BIM to BEM models which are essentially built on multiple high-performance envelope fabric for parametric analysis. Next simulation procedures (using BPS tools) are applied on the individually parametric model. The particulars of the simulation phases are specified. Also, the particulars of the base case model including materials data are elucidated in the previous section. Selecting a building envelope fabric with familiar energy properties and well-known features is significant as it permits the researcher to effortlessly examine and understand verdicts from repeating the diverse building modeling resources. This is also allowable for a thorough analysis of the probable in building fabric modeling for both sustainable and non-sustainable BIM atmosphere. To confirm the computational outcomes are truthful, real energy data is expended to validate the base case results which is explained in the next section. Lastly, compare and identify each scenario to perceive the optimum performance of building envelope materials.

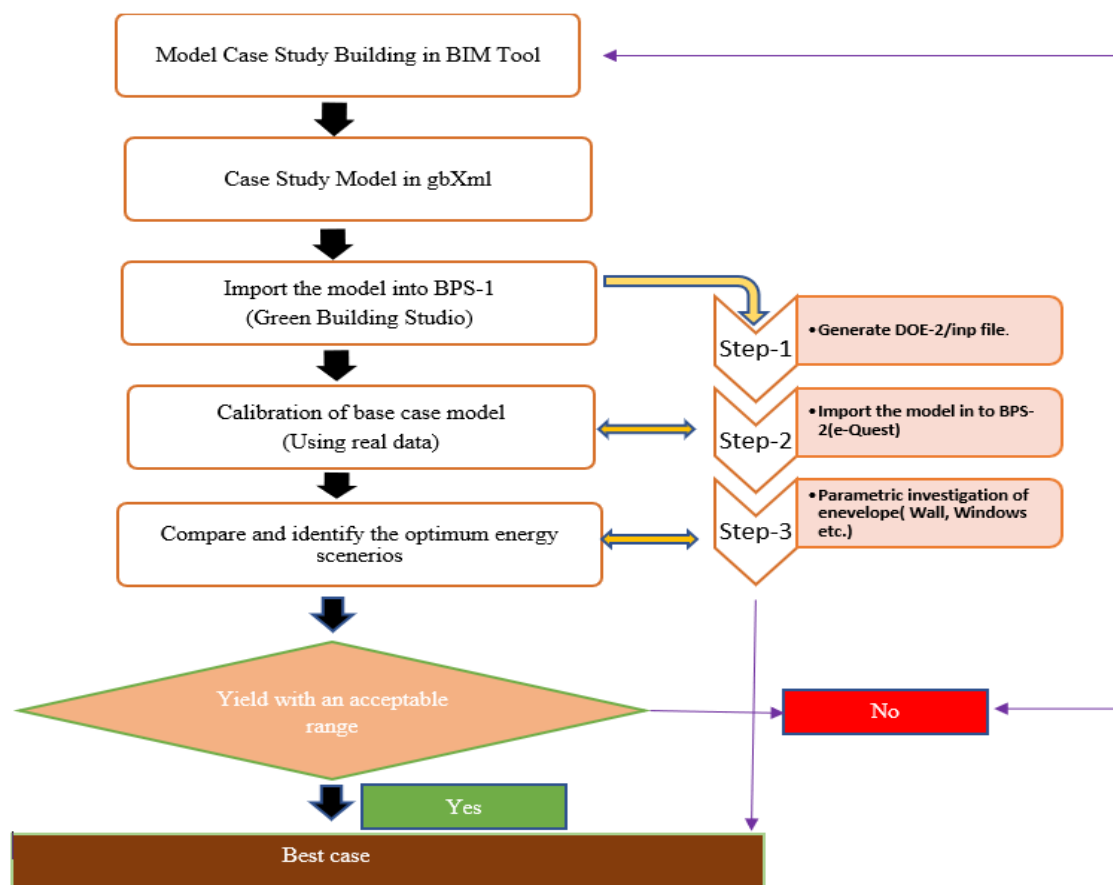


Figure 3. A conceptual framework

2.5 Materials Take-off

The detailed materials calculation such as quantity, type, area, and volume are automatically adopted using BIM software. As this is a parametric based model, so we can alter or modify any material information for any specific object if required [20, 21]. However, there are existing boundaries due to dependence on the Revit materials databank which is mainly built in the USA. All model making tools have default values for every constructing prerequisites that are building from several levels for floors, ceilings, walls, and roofs. For instance, Revit is most popular BIM tool, systematic model progress can be customized inside items, to suit selected envelope materials [20, 21, 22]. Numerous parameters such as thickness, thermal conductivity, emissivity, U value, specific heat, porosity, density, reflectivity, permeability, and electrical resistivity of the model are reachable to modify for in specifically selected materials. These materials data are then designated to the individual layer of building stuff like floors, roofs, walls, windows, ceilings, etc. and which are then combined to supply the standard performance.

2.6 Verification of the base case model

The aim of this verification was to equate with the real energy (kWh) data attained from the case study building. This energy data is practical, frequently called “factual” data. It is indicated most dominant and powerful tool as well as it can be applied in equating with reviewing data [23]. Furthermore, a study from Ryan et al [24] anticipated that energy simulation outcomes must be validated by equating with computed data for a real building. The energy simulation tool e-QUEST was preferred in this investigation for examining the envelope fabric. The simulation tools within e-QUEST are derived from the newest official package (e.g. e-QUEST 3.65.7175) of DOE-2, which is the utmost extensively familiar energy analysis engine. Based on the opinions, the energy (kWh) data of the case study building was equated to the energy simulated outcomes obtained from e-Quest. According to energy data obtained from the Facilities Management Office (FMO) of The Hong Kong Polytechnic University, the total annual energy consumption in 2017 was 1,10,15,838 kWh. The results generated by BPS presented in the baseline model suggest a total energy use 1, 06, 62, 937 kWh. The real value of 1, 10, 15, 838 kWh is about 3.2% higher than the computed value from the BPS tool (e.g. e-Quest). Reeves et al. [25] and Maamari et al. [26] reveals that the acceptable percentage error between calculated or empirical and computer simulation results must stay in the range $\pm 15\%$ for the energy software tool to be considered accurate. So, this calculated difference of 3.2% is clearly within the accepted range.

3. Results & Discussions

Mainly three categories envelope design stratagems were finally identified, namely, External Wall Redevelopment (EWR), External Wall Redevelopment (EWR) + Windows Redevelopment (WR)-1, External Wall Redevelopment (EWR) + Windows Redevelopment (WR)-2. Each category comprises 7 sub-categories including base case. Noted that, latent load is considered as a default value of BPS tools in this research meanwhile the particular envelope fabric designs will not have a noteworthy consequence on the hygrothermal performance of the space excluding when the interior dry bulb temperature falls under the dew point temperature, which infrequently occurs in the sub-tropical climate in Hong Kong.

The simulation results from table 2, exposed that with improved external wall design actions applied to the base case building, the yearly building energy can be lessened as much as 10.40% for EWR-3 which was developed with the combination of stucco (1 inch), insulation (2 inches), and clay tile (8 inches). Among other measures of adjusting external envelope adopting EWR-1 save up to 10.10 % which is part of a combination of brick, insulation, and concrete. Steel siding comprises a heavyweight concrete block (e.g. EWR-2) also shown a significant reduction in energy nearby 8.11%. The alternative strategy of fabric re-modification such as EWR-4, EWR-5, EWR-6, and EWR-7 has shown quite similar energy savings ranges from 5.92-6.30%.

Table 2. External Wall Redevelopment (EWR)

Construction	Materials Specification	Electric Consumption (kWh)/Year	Gas Consumption (kWh)/Year	Total (kWh)/Year	Energy Savings (%)
Baseline Design	4 in face brick with 8 in common brick (U=1.5499 W/(m ² K))	90,19,500	16,43,437	1,06,62,937	0
EWR -1	4-inch face brick, 2inch insulation, 4inch lightweight concrete block	76,43,900	19,42,590	95,86,490	10.10
EWR -2	Steel siding 0.06 inch, 2inch insulation, 12-inch heavy weight concrete block	78,55,200	19,42,590	97,97,790	8.11
EWR -3	Stucco 1 inch, 2 inches insulation, Clay tile 8 inch	76,11,600	19,42,590	95,54,190	10.40
EWR -4	Stone ½ inch, felt 3/8 inch, 2-inch insulation	8,048, 200	19,42,590	99,90,790	6.30
EWR -5	Finish 0.5 inch, 3-inch insulation, Finish 0.5 inch	80,54,300	19,42,590	99,96,890	6.25
EWR -6	Steel siding 0.06, 2-inch insulation, Common brick 8 inch	80,11,900	19,42,590	99,54,490	6.65
EWR -7	Steel siding 0.06, 3-inch insulation, Steel siding 0.06	8,089,300	19,42,590	1,00,31,890	5.92

From table 3, the Building Performance Simulation (BPS) assessments indicated that using the combination of External Wall Redevelopment (EWR) and Windows Redevelopment (WR)-1 considerably decreased the total energy consumption. The maximum energy saving of EWR and Double Low-E window comprises are 11.13%, 11.32% and 11.45% for EWR-1+ Double Glazing Window, EWR-2+ Double Glazing Window, and EWR-3+ Double Glazing Window, respectively. The results also disclosed that there is a similar reduction in energy for the EWR-4 (10.05%) and EWR-5(10.04%) which are united with double glazing windows. The lowermost yearly energy savings figure of 9.78% and 9.75 % for EWR-6 and EWR-7 combined with Double Low-E (e2=0.4) clear 6mm/13 mm air.

Table 3. External Wall Redevelopment (EWR) + Windows Redevelopment (WR)-1

Construction	Materials Specification (Windows)	Electric Consumption (kWh)/Year	Gas Consumption (kWh)/Year	Total (kWh)/Year	Energy Savings (%)
Base Line Design	Large single-glazed windows (U=5.5617 W/(m ² K), SHGC=0.86)	90,19,500	16,43,437	1,06,62,937	0
EWR-1+ Double Glazing Window	Double Low-E (e2=0.4) clear 6 mm/ 13 mm air	75,31,100	19,45,520	94,76,620	11.13
EWR-2+ Double Glazing Window	Double Low-E (e2=0.4) clear 6 mm/ 13 mm air	75,10,000	19,45,520	94,55,520	11.32
EWR-3+ Double Glazing Window	Double Low-E (e2=0.4) clear 6 mm/ 13 mm air	74,97,300	19,45,520	94,42,820	11.45
EWR-4+ Double Glazing Window	Double Low-E (e2=0.4) clear 6 mm/ 13 mm air	76,45,700	19,45,520	95,91,220	10.05
EWR-5+ Double Glazing Window	Double Low-E (e2=0.4) clear 6 mm/ 13 mm air	76,47,000	19,45,520	95,92,520	10.04
EWR-6+ Double Glazing Window	Double Low-E (e2=0.4) clear 6 mm/ 13 mm air	76,75,100	19,45,520	96,20,620	9.78
EWR-7+ Double Glazing Window	Double Low-E (e2=0.4) clear 6 mm/ 13 mm air	76,77,700	19,45,520	96,23,220	9.75

The mutual effect of External Wall Redevelopment and Double Reflective windows (D clear 6 mm/6 mm Air) shows the lower performance (table 4) than saving mentioned in the second category (table 3).

The maximum and minimum savings in this category are 9.46% for EWR-3 and 11.20% for EWR-7 combined with Double Reflective Window. From the overall results of view, the second category of fabric remodelling (mentioned in table 3) has shown the highest energy savings. Moreover, substitute shadings and window systems attained energy savings roughly 5% which is not listed here.

Table 4. External Wall Redevelopment (EWR) + Windows Redevelopment (WR)-2

Particulars/ Description	Materials Specification (Windows)	Electric Consumption (kWh)/Year	Gas Consumption (kWh)/Year	Total (kWh)/Year	Energy Savings (%)
Baseline Design	Large single-glazed windows (U=5.5617 W/(m ² K), SHGC=0.86)	90,19,500	16,43,437	1,06,62,937	0
EWR-1+ Double Reflective Window	Double Reflective D clear 6 mm/ 6 mm Air	75,58,500	19,42,590	95,01,090	10.90
EWR-2+ Double Reflective Window	Double Reflective D clear 6 mm/6 mm Air	75,36,100	19,45,520	94,81,620	11.08
EWR-3+ Double Reflective Window	Double Reflective D clear 6 mm/6 mm Air	75,24,200	19,45,520	94,69,720	11.20
EWR-4+ Double Reflective Window	Double Reflective D clear 6 mm/6 mm Air	76,77,000	19,45,520	96,22,520	9.76
EWR-5+ Double Reflective Window	Double Reflective D clear 6 mm/6 mm Air	76,76,700	19,42,590	96,19,290	9.80
EWR-6+ Double Reflective Window	Double Reflective D clear 6 mm/6 mm Air	76,00,400	19,45,520	96,45,920	9.54
EWR-7+ Double Reflective Window	Double Reflective D clear 6 mm/6 mm Air	77,09,000	19,45,520	96,54,520	9.46

The noteworthy alteration of building energy efficiency of fabric design can be clarified by considerate heat movements over the building systems. Cooling and heating loads, which is trustily underwriting to space cooling and heating energy usage, come from heat transfer mechanism through the building operation (e.g. internal loads) and the interaction between the external environment and building (e.g. exterior envelope). Heat can be expanded from the atmosphere in three key behaviours, such as conduction, convection, and radiation.

4. Conclusions

In the Hong Kong context, this work has scrutinized three approaches for dropping the building energy consumption of high-rise structures. The conceptual framework accelerates the process of integrating BIM and building energy modelling (BEM) into the design phase which permits repeated data exchanging, analyzing and comparing for further retrofitting or renovation process. Two representative fabric design for the real building, namely wall and window are selected to be examined through BIM to BPS methods. A significant verdict is that the annual building energy usage can be decreased significantly, as much as by 11.45%. The results also reveal that there is a large potential of energy saving adopting readily available technologies as well as more constructive design process under the existing building guidelines without yielding the longitudinal efficiency of the design.

The paper highlights the usage of Building Information Modelling (BIM) and Building Performance Simulation (BPS) framework for the energy assessment of educational building in sub-tropical climate. It's also recommended that; further study can be employed other types of buildings and climates to enhance the energy performance of building during its design and operation phase.

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