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USING BUILDING INFORMATION & ENERGY MODELLING FOR ENERGY EFFICIENT DESIGNS

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SUMMARY: *The construction industry has a huge impact on the environment in terms of noise, water and land pollution, traffic congestion and waste disposal. Another aspect of the construction industry impact on the environment is the increasing energy consumption. According to published research, buildings energy use is expected to increase by 32% by the year 2040. As a result, efforts have been directed toward improving green building awareness and the application of sustainability concepts in the design, construction and building management processes. In this research, using extensive simulations, the integration between Building Information Modeling methodology (BIM) and Building Energy Modeling (BEM) methodologies in order to effectively minimize the overall energy consumption of a residential building in the UAE is investigated by studying several design factors including: building orientation and windows type, size and distribution on the overall building energy consumption. Results show that to increase the modelled building's energy and financial efficiency, recommended changes to the initial design have to be done including changing the distribution of the southern façade and the type of windows glazing used. More specifically, there was a peak energy reduction of: 8% with a 180 degrees building orientation angle, 2% with a window to wall ratio of 15%, and 2% when double glazing windows were used. This work validates that the combination of BIM and BEM allows to enhance the overall building energy consumption efficiency and to further establish the needed sustainability goals through a generated 3D model.*

KEYWORDS: *BIM, BEM, Sustainability, Energy Efficiency, Simulation, Sustainable Construction.*

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1. INTRODUCTION

According to the Environmental Protection Agency (EPA, 2019), 600 million tons of construction waste was developed in the United States in 2018 alone and most of this waste ends up in landfills. Another aspect of the construction industry impact on the environment is the increasing energy consumption. According to the US Energy information administration studies, the construction sector will account for at least 21% of the total energy consumption in 2040 (WBSD, 2008). Apart from energy consumption, the construction industry is responsible of producing Greenhouse Gas emissions that would reach around 42.2 billion tons in the year 2035 with 288 million tons being produced in the UAE alone every year (British Petroleum Company, 2020). Also, another notable impact of buildings on the environment is the Building carbon footprint (CO_2) which is the total amount of greenhouse gases produced throughout the life-cycle of a building. . Greenhouse Gas emissions (GHG) is one of the major causes of Global warming (Adhikari et al., 2020). The concept of “Green Building” is defined by (Kibert, 2016) as “Building healthy facilities, designed and built in a resource efficient manner using ecological based principles during the whole project lifecycle”. Green Buildings’ main objectives are to minimize the impact of the construction industry to the surrounding environment by reducing the buildings’ carbon footprint (CO2 emissions) and reducing the energy dependency on fossil fuels, implementing sustainable concepts throughout the whole building lifecycle, improving the health of the building users and guarantee owners rate of return on their investment (Robichaud et al. 2011).

Knowing the effects of the construction industry on the environment and its major impact on the lives of human beings, in May 2007 Edward Mazria an American architect with the support of the American institute of Architecture (AIA), Architecture 2030 and the U.S Green Building community initiated the 2030 challenge (Ab Rahman et al., 2020). The challenge aims to carbon-neutralize all new building developments by the year 2030 by encouraging the global engineering community to adopt different goals and strategies in any new development to reduce or completely eliminate building energy consumptions. Implementing the 2030 challenge requires the involvement of all stakeholders involved in the building design and construction process. Although adopting passive energy systems in the building design is a major step towards a sustainable building design, the challenge encourages the use of only 20% passive energy systems (Solar system, Wind System, etc.). The remaining percentage must come from either altering the materials used in the design of the building to be more sustainable leading to less greenhouse emissions or by using an energy efficient design which depends on varying the orientation of the building, the size of the building openings (Windows, Doors and skylights) and/or the Mechanical/Electrical design of the building. One way of implementing the challenge is through the use of Building Information Modelling (BIM) concept (Seyis, 2020). The Building Information Modelling (BIM) concept is one of the most efficient tools to integrate building data and facilitate the management of the building information throughout the whole building lifecycle (Lu, et al. 2020). Building information modelling can be used to facilitate communication and information sharing between all project stakeholders and architecture, engineers and contractors (AEC) teams. It can also provide a 3D visualization of the project and detailed material quantities which will lead to a detailed cost and time estimation. Based on surveys done by the NBS national BIM survey; 70% of the people who participated in the survey stated that BIM helped reduced 33% of the initial cost of construction and lifecycle cost of the project as a whole, 60% of the survey population believed that BIM reduces the overall time of the project, from initiation to closeout, by 50% (Wong et. al, 2015). The time and cost efficiency increase are caused by the clash detection advantage of BIM. In addition to all the managerial benefits of Building information modelling concept, BIM can be used as a tool to support sustainable decision-making process. Through BIM, minimization of waste material can be achieved, buildings and construction energy consumption can be minimized and reduction of greenhouse gas Carbon emissions (CO_2) can be noticed (Xu et al., 2020).

“Green BIM” is the process of connecting Building Information Modelling to sustainable construction concepts and is defined as a process to generate and coordinate building information data to enhance the building energy consumption efficiency and to establish the needed sustainability goals through a generated 3D model (Wong et. al, 2015). Green BIM can be very helpful in supporting the building sustainability aspects by minimizing the construction waste generated due to the limited coordination between departments, rework and last-minute changes. An example of BIM success in minimizing waste is the Shanghai tower in China where the project achieved only 4% waste rate compared to the 10% waste average level in China (Jiao et al., 2013). BIM can also be used to minimize the building energy consumption by forecasting the building energy needed for lighting, equipment loads, heating and cooling. The simulation of a pre-developed building using BIM can help developers and designers study various design alternatives to minimize the energy consumption. It can also be used to study the impact of implementing renewable energy resources into the building and study the financial feasibility of the various alternatives. Saving energy and emphasizing the need to reduce fossil fuels resources and to replace it by renewable energy resources has been of great importance over the years. For example, 71% of the US energy is consumed by buildings, out of this percentage 30% is used for heating and cooling (Li and Wen, 2014). Also, at a local context, as per the Emirates Green Building Council, UAE energy consumption is expected to increase by 4% to 6% annually with the approach of EXPO 2020 (EGBC, 2020)

To achieve energy efficient buildings goal, Building Information Modelling (BIM) must work hand in hand with Building Energy modelling (BEM). BEM is a tool to simulate the building energy consumption and thermal charge calculations. BEM has been around since the 1980's but the current developed versions have the capacity to develop calculations taking into consideration the building material used and the ventilation, cooling and heating system proposed. Many BEM modelling tools are currently available including AECOsim Energy simulator, Revit Insight and ECOTECT (Building Energy Modeling, 2020). In these programs, information about the location of the building, average weather temperatures of the area and information about the ventilation and cooling system used must be used as inputs. Also, information about individuals using the building and peoples' thermal gain must be obtained, which is the amount of energy emitted by each person inside the building. The integration between BIM model and the BEM model can generate information regarding the building carbon dioxide footprint emissions, and the building Thermal transmittance (U value) which is the speed of heat transfer through a unit of time and surface of the construction element. Although there have been an abundant number of recent researches on the use of BIM for building energy optimizations, there are evident gaps in combining multiple factors for a rigorous analysis in one study as previous research studies have explored building factors in isolation. Existing research studies have only studied specific design factors and have not presented a complete simulation framework combining both BIM and BEM in order to investigate the impact on energy consumption of several building design parameters combinations. In this research, we will research, through extensive simulations, the integration between Building information modelling methodology (BIM) and Building energy modelling methodology (BEM) in effectively minimizing the energy consumption of a residential building by studying the mutual impact of several design factors including: building orientation and windows glazing type and size on the building energy consumption. More specifically, this study aims to address the research gap through a case study on a single family house.

2. LITERATURE REVIEW

2.1 Background

One way of achieving green sustainable buildings is the use of Building Information modelling (BIM) methodology in the design stages. Although the concept of building modelling first appeared in scientific research papers in the mid-80s (Aish, 1986) the term Building information modelling in the sense known of today first appeared in (Van-Nederveen et al., 1992) and the concept of BIM did not become widely used until the early 2000s where huge software companies such as Autodesk and Bentley Systems started real implementations. BIM can be considered as a 5D intelligent model containing the 3D physical component of the building (width, depth and height) with cost and time considered as the 4th and 5th dimensions. Construction waste can also be minimized through the use of BIM due to less rework, higher level of coordination and communication between departments, higher integration between the building systems and subsystems during the construction phase (Jiao et al., 2013). Green BIM is the concept related to the connection of green Buildings and BIM methodologies focusing on three related dimensions; the project phases, the green attributes and the BIM attributes (Wong et. al, 2015). To achieve Green BIM, the BIM model needs to be connected to a Building Energy Model (BEM) that aims to calculate the building's thermal change and energy utilization. The Building Energy Modelling (BEM) concept has been used in the design stage for energy analysis since the 1980's and it has been further developed to account for the use of renewable energy and to accommodate solutions for energy conservation.

The BIM model and the Building Energy Model (BEM) must have a way of communication to ensure the flow of information between the two tools; this kind of information flow follows the concept of Interoperability. Interoperability is defined as the effective ability to transfer project data and information between different domains and platforms without replication (Eastman, 2011). Building Energy Model (BEM) is used to analyze and evaluate design alternatives of systems, subsystems and components to make sure the building design meets the energy standards (Jeong et al., 2016). Building energy performance using sets of assessments and evaluation processes seeks to determine the building energy usage, cost of energy consumed in the building and determining the areas where high energy consumption exist in order to provide solutions and options for minimizing the usage and integrating passive energy systems into the design (Yuan et al., 2011).

Energy Building Analysis to be taken into consideration when evaluating the building energy performance include: Solar and Thermal Energy, which is the analysis of the building's ability to store heat without being affected by the temperature fluctuations; Building Ventilation and HVAC system, Day Lighting evaluation, Building Orientation and Building Envelope analysis (US GSA, 2009). Energy Design Optimization attempts to minimize the total cost of ownership and maximize energy savings by identifying unique designs before building construction or retrofit begins. Both **Energy** Building Analysis and Energy Design Optimization aim to reach the thermal comfort zone of the building occupant while insuring the minimization of energy loss and the optimal usage of natural resources to minimize the energy impact on the surrounding environment. Egwunatum et al. (2016) showed that the integration between a BIM model and an energy analysis model helped into delivering a building that is 103% more efficient. Many factors affect the Building energy usage such as the surrounding climate, nature and number of occupants. Zoning the building as per the occupants' activity level is considered one of the major inputs to the BEM model (Thermal Blocks). Another factor affecting the building energy usage is the building envelope. Since the building envelope acts as a connection point between the internal and external environment and since it works as a barrier to heat, sunlight and wind, it must be designed in a way to achieve the optimal energy performance possible. The building envelope consists of the building roof, walls, openings (windows, skylights and doors). One way to optimize the building envelop is by wisely choosing the building material based on its characteristics and form, and the use of sustainable and durable material.

2.2 Related Work

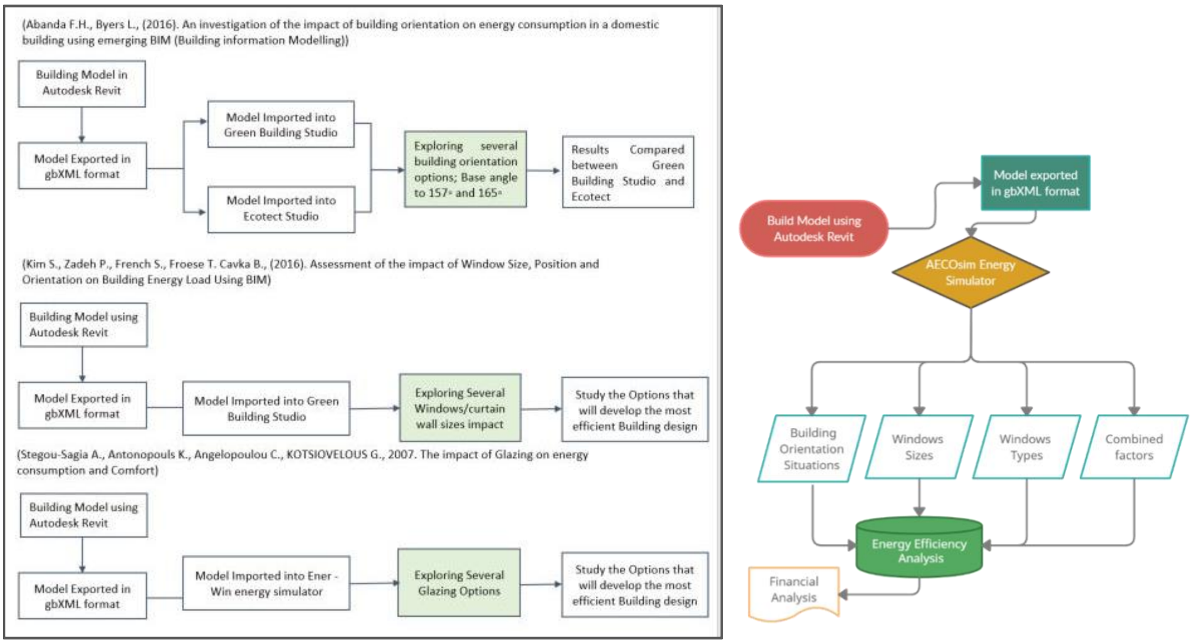
Several research works have investigated the use of various material combinations in walls and roofs in reducing the building annual energy consumption using BIM. For example, the Shoubi et. al (2015) concluded that the use of double brick cavity plaster is more energy efficient than using a brick plaster as it saves up to 1000 kWh annually. Also, Kim et al. (2016) discussed the effect of window size, position and orientation on the building energy load. The results showed that the orientation of the window has its biggest impact when the windows faced the East taking into consideration that the result can be changed by changing the building size or relocating the Building under study. Another study by Stegou-Sagia et al. (2007) examined the effect of the glazing area and percentage on the occupant's thermal comfort and the building energy usage. The building that they used for their study consisted of 20% double glazed grey tinted windows with different scenarios. They noticed that changing the glazing from tinted to grey caused the energy consumption to increase due to the increase in the building's solar gain. Aksoy et al. (2006) suggested that choosing the optimal building shape and orientation will yield to an increase in energy efficiency by around 36%. Abanda et al. (2016) discussed the effect of building orientation on the annual energy consumption. Building orientation is vital when depending on the solar light especially during the colder season where choosing the optimal building orientation will yield a maximum solar gain. Also, the integration between BIM and BEM is proving its capability to reduce energy consumption and meet the sustainable requirements of the different available green standards. More recently, aligned with the Saudi Vision 2030, Ahmed et. al (2020) examined the viability of retrofitting houses in Saudi Arabia using BIM by introducing several Energy Efficiency Measures (EEMs).

Also, recognizing the Benefits of BIM, Dubai Municipality recently issued a mandate rule in using BIM in all its large buildings and all specialized buildings such as schools, hospitals and governmental entities (BIM law and regulation in the UAE, 2018). While BIM is widely used in the Gulf Cooperation Council (GCC) countries, empirical research studies on the implementation of BIM in green Buildings incorporating different factors are not available. This research study aims towards the implementation of BIM in reducing energy consumption and Carbon Footprint for similar Buildings located in the GCC who share similar climate, weather and cultures. More specifically, the research in this study attempts to complement the literature as it will study the impact of multiple design factors on the same building using a combination of BIM and BEM. Significant differences between the proposed research methods and previously published researches are shown in Fig. 1(a). To study the energy behavior of the building, Building Information Modelling (BIM) and Building Energy modelling (BEM) are integrated in a concept called BIM2BEM. The role of this integration originated from the inadequate outputs of BEM programs when being used in isolation lacking vital information from all parties involved in the building designs. The integration is considered a semi-automated process since some information must be added manually including the material thermal properties along with the building properties that might affect energy consumption parameters. The use of the BIM model will allow the BEM program to access a large digital data library leading to a reliable energy efficient design. Also, the integration will allow the designer to take sustainable, green decisions while taking into consideration the time, cost and risk factors.

3. RESEARCH METHODOLOGY

3.1 Software tools and framework

A simulation/case study approach is investigated using Autodesk Revit as the BIM program and AECOsim Energy Simulator as the Building Energy Modelling (BEM) program. The AECOsim Energy simulator allows for a fully agreement with the industry standards through a fully automated integration of mechanical, electrical and energy performance design capabilities. On developing our simulation, we refer to the ASHRAE society' set of standards and guidelines to assist in the design process (ASHRAE, 2020). For example, ASHRAE 90.1 standards covers the following building elements: Building Envelop (wall thickness, roof insulation and glazing requirements), HVAC system (minimum efficiency, limitation and re-usage of energy loads); Lighting (external and internal lighting to match occupants' comfort); Power (power usage efficiency and energy monitoring). To connect the model developed in Revit to the energy simulator software AECOsim, the concept of interoperability was used. One application of the Interoperability concept is the gbXML file which stands for the Green Building XML file. The gbXML format allows for the exchange of both the geometry of the building and all related information connected to the geometry from schedule, material properties, cost and any non-geometric data of the project. The gbXML format is widely used in practice as it is efficient and easy to use and is considered a form of the famously used IFC (Industry Foundation Classes) format. gbXML format is mainly used to transfer and concentrate into the building thermal and energy related factors while IFC models the entire building geometry, material characteristics and schedules. Although gbXML and IFC are very similar in their core concept, IFC does not take into consideration the energy characteristics of the building. This integration will allow us to study several previously unexplored factors affecting the building energy performance including: the orientation of the whole building, the size and location of the building windows and doors, and the impact of glazing material used. Several research studies have explored these factors in isolation. Our research is different as it will study the energy and economic impact of these factors on the same building using both BIM and BEM as shown in Fig. 1(b).



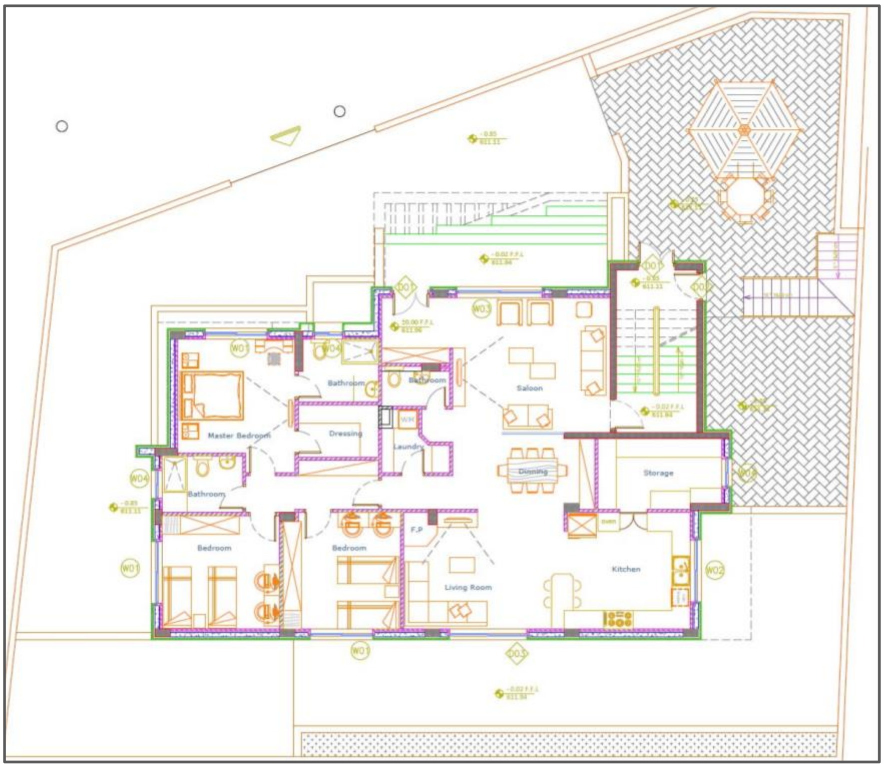
(a) *(b)*

FIG. 1: (a) Comparison between other research works (b)Research framework of this study.

3.2 Description of the building under study

To evaluate the effectiveness of the integration between the Building Information Modelling Software and the Building Energy Modelling in reducing the energy consumption of the building, a model of a two-story residential building located in Abu Dhabi, United Arab Emirates was created as shown in Fig. 2(a). The building modelled is a two story multi-family building with one floor being occupied by one family. Each floor consists of 3 bedrooms; 1 master bedroom and 2 smaller bedrooms, an open kitchen with a dining area, a living area and a saloon and three Bathrooms. Both floors have a very similar layout. The layout of the floors can be found is Fig. 2(b).

(a)



(b)

FIG. 2: (a) 3D rendered shot of the building modelled; (b) Building Floor Layout.

3.3 Modelling procedure

To start the energy consumption analysis of the building, the model needs to be modelled first using Autodesk Revit (BIM-tool) and then exported to the AECOsim Energy Simulator (BEM-tool) using the following steps: First, the modelling procedure followed the 2D AutoCAD drawings provided by the architect of the building. While modelling, information on the material used for each building element were added to the model to develop a smart comprehensive model as shown in Fig. 3.

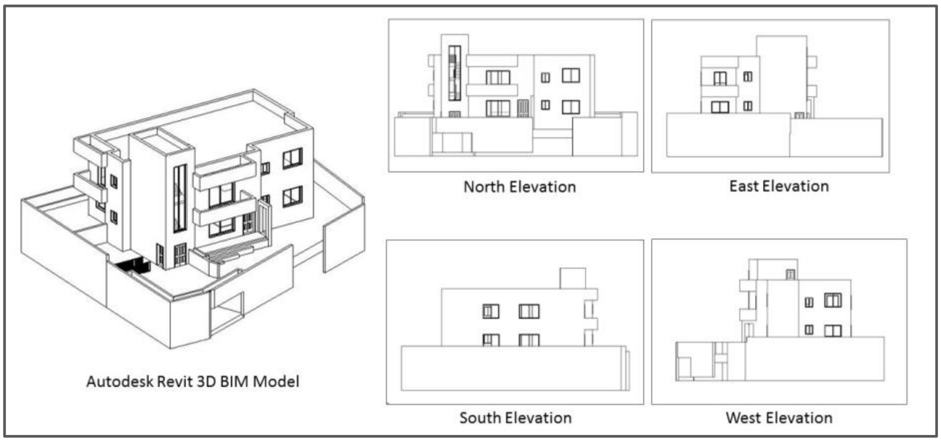


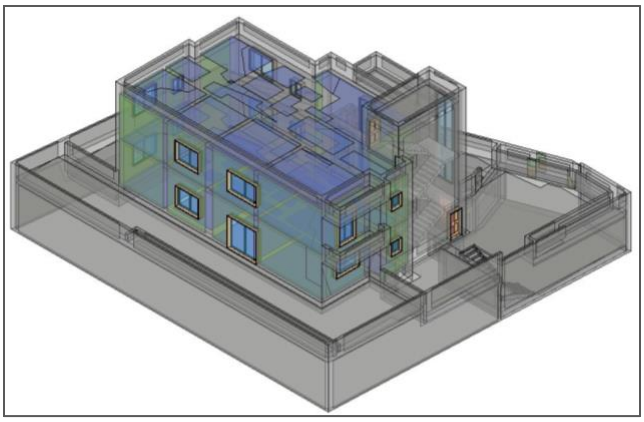
FIG. 3: Autodesk Revit BIM model

Information added in this step included:

1. ***Material Used***: including the material name, class, description and manufacturer. This information was used to identify each material in the material take-off schedule which is used for pricing the project and scheduling the acquisition of the material on site.
2. ***Mechanical Properties***: including material density, shear modulus, Poison's ratio, Young's modulus, material yield strength, tensile strength, and shear strength. This information is needed in the building design process.
3. ***Thermal Properties***: are critical components in measuring the building total energy consumption. Material thermal properties identified in include:
    a) *Thermal Conductivity (K-Value):* which measures the ability of the material to conduct heat in Watts per Meter-Kelvin (W/M.K).
    b) *Thermal Emissivity*: which is an indication of the material's ability to effectively emit energy and is measured as a ratio from the perfect case of Thermal emissivity of 1 for a perfectly black object.
    c) *Electrical Resistivity (ρ):* which studies the ability of the material to oppose the flow of the electrical current in ohm-meter (Ω·m).
    d) *Specific Heat (heat capacity)*: which indicates the amount of heat per unit mass required to raise the temperature of the material by 1 degree and is represented by the unit (J/kg. C◦).
4. ***Building Location***: The Building coordinates were entered to the system (Latitude 24.3896293640137, Longitudinal 54.6721076965332) and that automatically identified the weather data to be used in the energy calculations (received from the closest weather station). For our study the closest station to our building was the Abu Dhabi international airport weather station. Weather information includes:
    a) *Dry Bulb Temperature* (highest expected monthly temperature): is the weather temperature taken by a thermometer shielded from any moisture or radiation linked with the thermal comfort of the building.
    b) *Wet Bulb Temperature* (lowest expected monthly temperature): is the weather temperature taking into consideration the humidity and air rate of evaporation.
    c) *Mean Daily Temperature*: is the mean temperature of the difference between the highest expected temperature and the lowest expected temperature each month.

Once the model of the building was done and all material properties and the building location/weather were identified, the building energy analysis procedure started by identifying a total of 28 model Spaces. This was important to accurately determine each space heating and cooling requirements based on their properties and usage. Information added while identifying the Space included: Level, upper limit (an indication where the Space ends), limit offset (space boundary points), general information (space number, name, dimensions), occupancy, type (the use of the space), and people (number of people that will be using the space). Although Revit provides good energy configuration, energy related parameters were configured in the AECOsim energy simulator instead which is more compatible with the ASHRAE requirements and provides better accuracy.

After identifying the building Spaces and Space types, the Software Energy setting need to be set up to generate an analytical energy model in Revit (as shown in Fig. 4) as gbXML extensions only export energy models as follows. Conceptual masses and Building elements were chosen (mode). The ground level was identified as the ground plan as the building under study does not have any underground floors. Also, since this energy analysis procedure can be done for both new construction buildings or retrofitting projects, a specific project phase was identified (new construction). Finally, the default values for the analytical space and surface resolution variables were chosen to obtain an efficient balance between the accuracy of the energy model and the Autodesk Revit processing time. Other advanced settings based on the data from ASHRAE 90.1/2-2010 were configured including: Building type (Multifamily residential building), Building operating schedule (a 24/7 schedule), HVAC system (Central VAV, HW Heat, Chiller 5.96 COP, Boilers 84.5 eff). At this stage the Autodesk Revit BIM model is ready to be exported into the gbXML format using the analytical energy model and imported to AECOsim Energy Simulator as illustrated in Fig. 4.



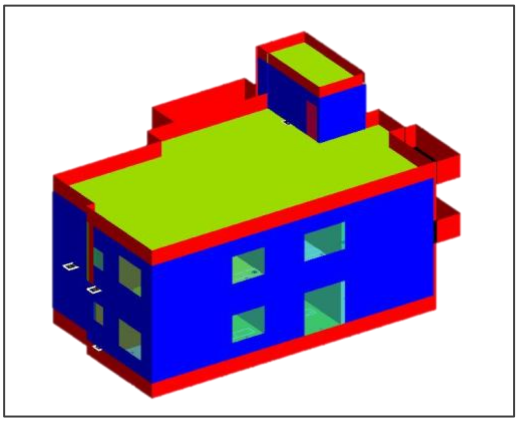


FIG. 4: Autodesk Revit Analytical Energy Model and AECOsim Energy Simulator Model

4. SIMULATION AND ANALYSIS

Prior to simulation analysis, the space energy properties were configured as per the guidelines in (Grondzik, et al 2014, Rea, 2003) including:

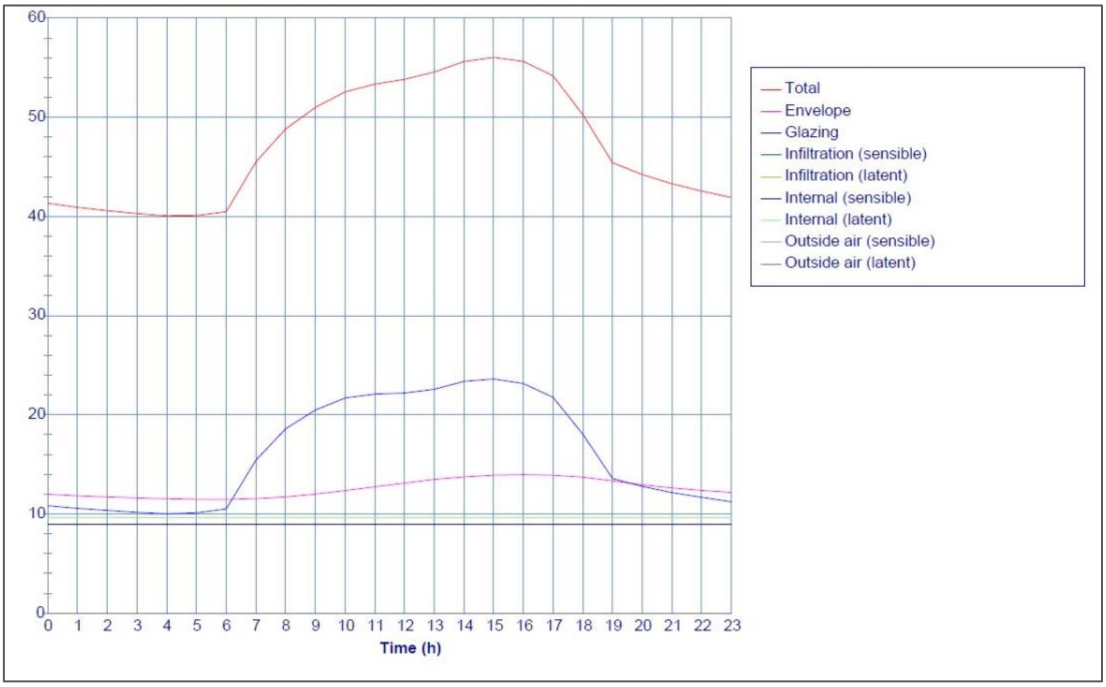
- ***Lighting properties***: Illumination per area (5.4 Watt/m^2), end-usage category (lightly conditioned), allowance (with added decorative lighting), room area, luminaire category (recessed fluorescent luminaire lighting), Return air fraction (assumed to be 0), fraction radiant/visible/replaceable (0.37, 0.18 and 0.45 resp.). The parameters assume that no lighting heat is transferred to any adjacent rooms.
- ***Occupancy properties***: Number of people mode (Absolute mode with a family of six people), activity type (Seated at rest Office work, Walking, Light work, Medium work, Heavy work added depending on what is expected from the occupants of the Space), body latent, body sensible, and body convective.
- **Gains Properties**: Design level calculation method (11 watt/m^2), fraction latent/radiant/lost (0.5, 0.7, and 0.5. resp.)
- ***Ventilation & Infiltration properties***: Design flow rate calculation method (flow rate per person of 1.1 m^3/s), ventilation type (natural ventilation), fan pressure rise (400 Pa), fan total efficiency (0.6) and air flow rate per room (0.00016 m^3/s).

The orientation of the baseline Building is assumed to be at 0.00 degrees from the North with vertical single glazing percentage between 0% and 10%. During the simulation, only the factor under investigation was varied while all other factors were kept constant. The analysis was done for the Month of August considering it is the Hottest

Month of the year in the UAE. Running the energy simulation analysis of the baseline model are shown in Fig.5(a) indicating the peak energy consumption of 56.04 KW (at 03:00 PM and at 43.9 degrees Celsius).

Sun Time (h)	Outside temp. (°C)	Envelope (W)	Glazing(W)	Infiltration(W)		Internal(W)		Outside air(W)		Total load(W)
				Sensible	Latent	Sensible	Latent	Sensible	Latent	
0	29.2	11992.75	10836.92	0	0	8919.07	9589.09	0	0	41337.83
1	28.4	11842.82	10568.17	0	0	8919.07	9589.09	0	0	40919.15
2	27.9	11720.85	10363.48	0	0	8919.07	9589.09	0	0	40592.49
3	27.4	11621.15	10163.11	0	0	8919.07	9589.09	0	0	40292.41
4	27	11536.63	10022.45	0	0	8919.07	9589.09	0	0	40067.24
5	27.4	11476.17	10115.61	0	0	8919.07	9589.09	0	0	40099.94
6	28.6	11466.83	10505.58	0	0	8919.07	9589.09	0	0	40480.56
7	31.7	11553.36	15434.75	0	0	8919.07	9589.09	0	0	45496.27
8	35.1	11722.87	18590.35	0	0	8919.07	9589.09	0	0	48821.38
9	38.2	12004.3	20488.51	0	0	8919.07	9589.09	0	0	51000.98
10	40.9	12358.44	21696.88	0	0	8919.07	9589.09	0	0	52563.48
11	42.7	12744.57	22093.07	0	0	8919.07	9589.09	0	0	53345.8
12	44.1	13118.87	22202.62	0	0	8919.07	9589.09	0	0	53829.65
13	45	13485.36	22575.35	0	0	8919.07	9589.09	0	0	54568.87
14	45	13738	23374.06	0	0	8919.07	9589.09	0	0	55620.22
15	43.9	13915.07	23617.45	0	0	8919.07	9589.09	0	0	56040.67
16	42.5	13968.37	23157.2	0	0	8919.07	9589.09	0	0	55633.73
17	40.7	13914.02	21761.04	0	0	8919.07	9589.09	0	0	54183.22
18	38	13713.11	18051.32	0	0	8919.07	9589.09	0	0	50272.59
19	36	13337.89	13574.5	0	0	8919.07	9589.09	0	0	45420.55
20	34.4	12933.95	12783.93	0	0	8919.07	9589.09	0	0	44226.04
21	32.8	12629.57	12158.43	0	0	8919.07	9589.09	0	0	43296.17
22	31.5	12374.44	11683.65	0	0	8919.07	9589.09	0	0	42566.24
23	30.2	12171.67	11227.23	0	0	8919.07	9589.09	0	0	41907.05

(a)



(b)

FIG. 5:(a) Base model total energy results. (b) Detailed representation of the required energy consumption of the different attributes' contributions.

This is expected considering that the highest temperature experienced is at 12 PM, 1 PM and 2 PM. Also, heat gains expected from the building glazing and the building envelope are highest at 3 PM for the Building glazing (23.9 KW) and at 4 PM for the building Envelope (13.96 KW). Fig. 5(b) illustrates the required energy needed at each hour of the day with the exact energy contribution of each factor.

4.1 Building orientation effect on peak energy consumption

10 scenarios of different building orientation angles were investigated. Starting with a building orientation of 0.0◦ from the north, an increment of 45◦ to the building orientation were simulated and the resulting building energy consumption, peak hours, percentage from envelope and percentage from glazing were calculated as shown in Table 1 and Fig. 6. It can be noted that a building orientation angle of 180◦ from the north showed the least peak monthly energy consumption of 51.4 KW when all other variables were kept constant in the simulation. This represents an 8% decrease in the peak energy monthly consumption compared to the base scenario. It can also be noted that the peak hour was at 2 PM for this scenario compared to a peak hour of 3 PM for the base scenario.

TABLE 1: Energy Rates when changing the building orientation

Angle	Peak-Energy-KW	Peak hour	Envelope %	Glazing %
0	56.04	15:00	24.8	42.1
45	59.85	16:00	23.3	45.8
90	61.273	16:00	22.5	47.2
135	59.7	16:00	22.9	46.1
180	51.4	14:00	24.7	41.9
225	57.8	16:00	23.5	44.5
270	59.47	16:00	23.0	45.7
315	59.3	16:00	23.4	45.4

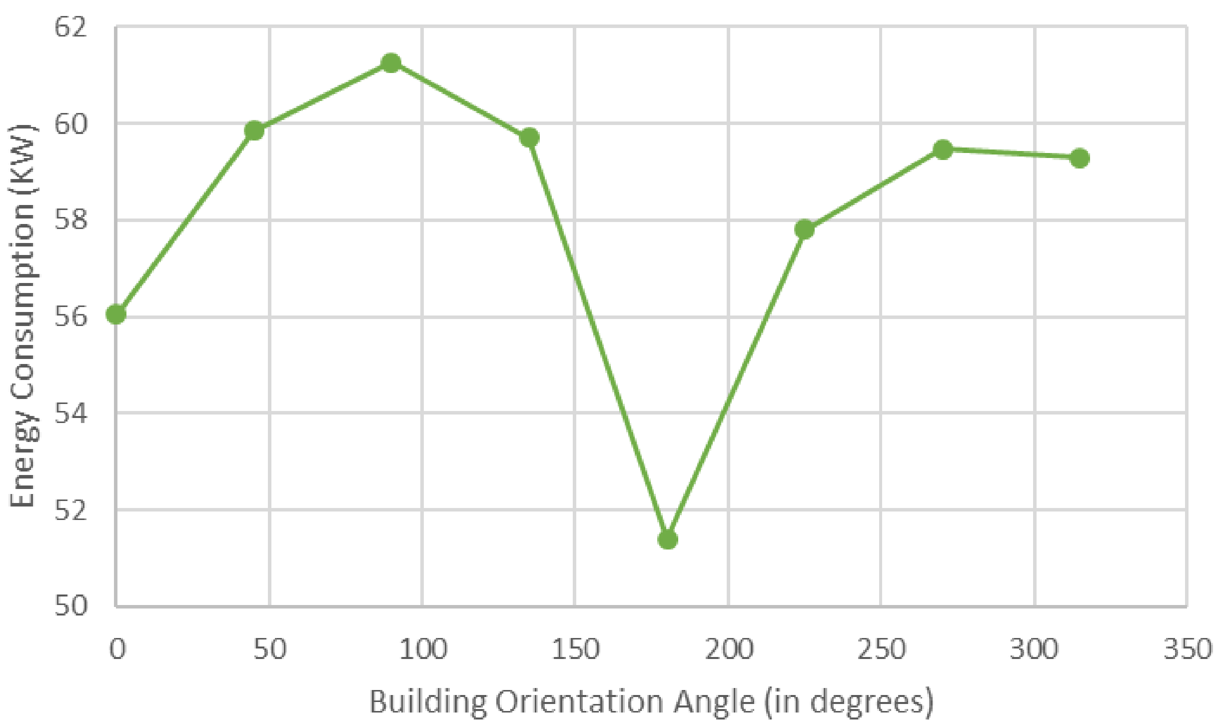


FIG. 6: Effect of building orientation on monthly peak energy consumption.

4.2 Building windows size effect on peak energy consumption

In order to control the simulation process, we studied the impact of the window size change of the Southern elevation of the building under study. 3 scenarios of 3 different windows to wall ratio (WWR) were studied. The Base line model (as shown in Fig. 5) with a 20% WWR was used for comparison. First the WWR was reduced from 20% to 15% to study the impact of the window size reduction on the peak energy consumption of the building. A 1.4% reduction in monthly peak energy consumption from 56.04 KW to 55.25 KW was recorded.

Also, to study the impact of window location and building elevation glazing distribution, the number of windows was increased from three windows and one window door to seven windows to one window door while keeping the window to wall ratio at 15% by reducing each window glazing area. Redistributing the glazing area resulted in a reduction of the building monthly peak energy consumption from 56.04 KW to 54.87 KW i.e. a reduction of 2%. The redistribution of the windows glazing increased the building energy efficiency by reducing the glazing gains. To fully understand the impact of window sizes on the building monthly energy consumption, the glazing area of the southern elevation was increased to 25% and 30% respectively as shown in Fig. 7. This resulted in an increase in peak energy consumption from 56.04 KW to 57.04 KW, 58.29 respectively. This also demonstrated that the windows glazing's monthly energy consumption contribution is 41.4% and 43.13% respectively.

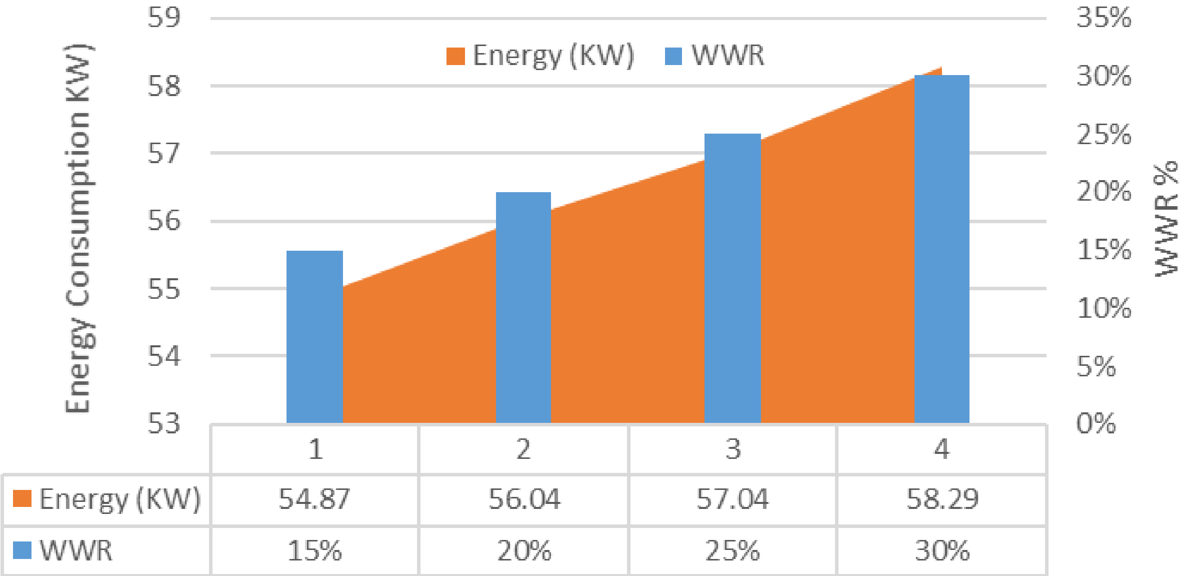


FIG. 7: Effect of different WWRs on energy consumption

4.3 Building windows type effect on monthly peak energy consumption

The final factor impacting the building monthly energy consumption to be considered in the research is the effect of the windows glazing type. The model was originally generated assuming the windows type used are single glazed with glazing percentage of 0 – 10%. A 2% reduction in the monthly energy consumption was noticed when switching to double glazed windows with 0 - 40% glazing percentage. Peak energy consumption was reduced from 56.04 kW for the Baseline model to 54.9 kW. We also noticed that the reduction of the energy consumption was solely due to the reduction of the heat gains from the glazing component of the building. The peak energy consumption hour remained at 3 PM. The reduction of the Energy consumption was expected as the double-glazing windows reduce the building heat loss and works as an insulation component to the building.

4.4 Overall energy and financial analysis

In this section, a study on the financial feasibility of the changes occurred to the modelled building are studied. Changing the orientation of the building does not affect the initial construction cost. Hence, no change in the cost of the materials used in the construction stage is noticed. Fig. 8 illustrates the resulting total monthly energy consumption and associated financials concerning the different recommended modifications in the building design. Energy consumption rates were based on the Abu Dhabi Electricity Distribution company Tariff rates for Expats houses which is 30.5 fils/kWh (1 AED=100 fils, and 1 USD=3.675 AED). We can infer the following:

- When all building parameters were kept the same with only one modification, there was a total monthly building energy reduction (and therefore a reduction in the monthly electricity fees) of: 1.27% when the building orientation angle was increased to 180 degrees from the north, 0.82% when a double glazing window was used, and 0.51% when the window to wall ratio was decreased to 15%. It is evident that the distribution of the windows through the elevation of the building is more energy efficient than concentrating the windows in one area.
- To analyze the combined effect of the parameters that exhibited improvements in building energy efficiency, another simulation scenario was investigated where the building orientation angle was 180 degrees, double glazing windows were used and the WWR was 15%. This resulted in an overall building energy reduction of 2.24% which is quite significant to say the least.
- Other configurations did not show any improvement on the energy consumption and therefore are not recommended.

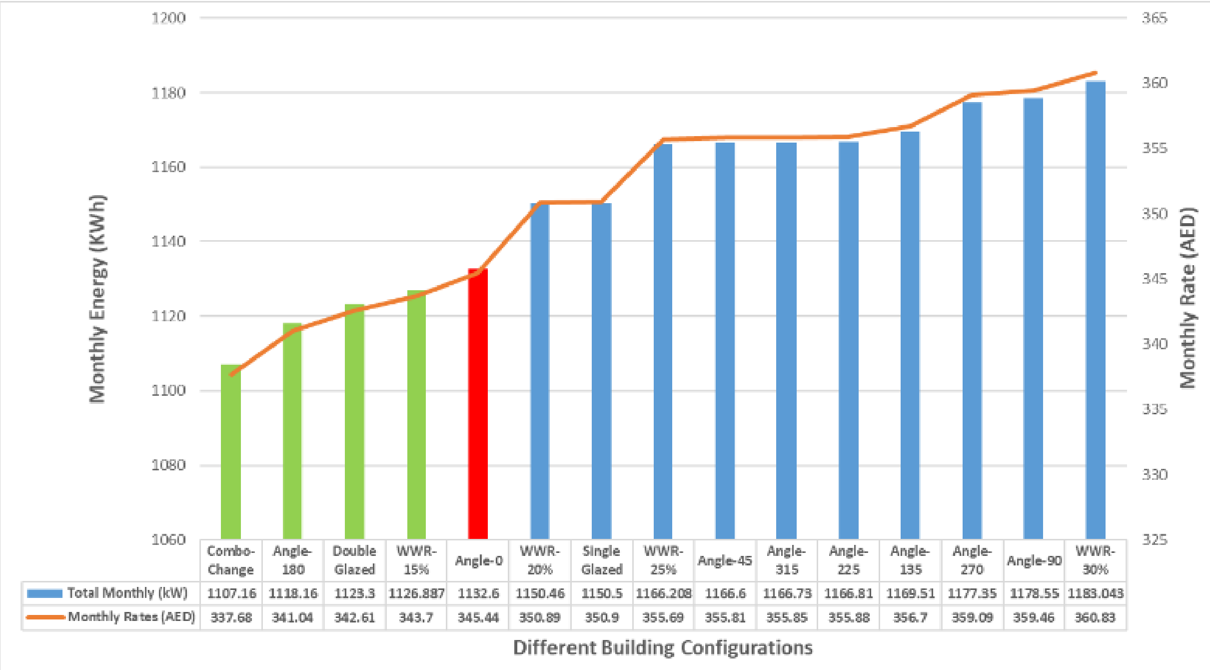


FIG. 8: Different configurations' effect on the monthly energy consumption (KWh) and the rate (AED)

5. DISCUSSION AND CONCLUSSIONS

Analyzing the factors that have an impact on the energy expenditure in a building is very significant in future sustainable designs. Building Information Modeling (BIM) has been recognized as one of the prominent simulation tools to assist designers, architects, and engineers during the design and pre-construction stages to assess performance factors. The main research objective in this paper was to rigorously analyze the previously unexplored combined effect of multiple building design attributes applied on a real two story multi-family building prior to construction located in the UAE. The integration of BIM and BEM (Building Energy Modeling) expanded the analytical results as it combined the strength of both tools. Results indicated that variations in configurations of the building orientation angle, windows types used, windows sizes or windows distribution have different positive implications on the peak energy consumption of the building and also on the total monthly building energy consumption.

More specifically, while keeping all building parameters constant, increasing the orientation angle of the original building design (which was 0 degrees from the north) by 180 degrees (hence pointing towards the South) resulted in an 8% reduction in peak energy consumption and 1.27% reduction in the total monthly building energy consumption. Similarly, decreasing the window to wall ratio (WWR) to 15% resulted to 0.5% overall energy consumption reduction. The redistribution of the windows to cover different locations of the elevation while keeping the total windows to wall areas fixed reduced the total energy consumption of the building. This was due to the fact that window areas covered different rooms without the need for artificial lighting and hence increased the building's natural ventilation system reducing the need for more energy for ventilation. Also, double-glazing windows impacted the energy consumption positively as they work as insulation materials. Finally, the combined effect of multiple configurations was analyzed indicating a positive energy and financial impact.

The results of this study are very significant as they will assist future researchers and practitioners in the field in making decisions on future sustainable building designs. Considering our analysis was based on a small building design during one month, future studies need to explore mega building designs over the course of a year. Also, other factors need to be simulated including building surroundings, build forms and functions among others.

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