Journal Home Page: https://sjes.univsul.edu.iq/

Research Article:

Energy Consumption in Residential Buildings Located in Rural Areas Through Utilizing BIM: Effect of Building Materials

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Article Information

Article History:
Received : September , 28th ,2026
Accepted : January,22nd ,2026
Available online: April, 2026

Keywords:
BIM, Energy Consumption, Rural Areas, Building Materials

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DOI https://doi.org/10.17656/sjes.10201

Abstract

Building Information Modeling (BIM) is increasingly recognized worldwide as a powerful tool that enhances productivity in the construction industry. By digitally representing building data, BIM helps reduce construction time and costs while improving project quality. This study investigates energy consumption in residential buildings located in rural areas of Iraq using BIM tools, specifically Revit and Insight 360°. In this study, three houses constructed with different materials were analyzed for their energy performance. Energy consumption was assessed using BIM simulations, and indoor temperature was measured manually over a 315-minute period using thermometers. The results showed that the average Energy Use Intensity (EUI) for house (01), house (02), and house (03) was found to be 145, 162, and 170 kWh/m²/year, respectively. These simulation results closely matched the recorded temperature data in terms of energy loss, supporting the accuracy of the software's predictions. Based on the findings, it is recommended that rural construction projects prioritize materials with better thermal insulation to significantly reduce energy consumption.

1- Introduction

During the past three decades, housing has become a global issue due to the increased urbanization, population growth, and economic activity [1]. These issues have affected the demand for improving building energy performance worldwide. According to Hannah Ritchie [2], more than half of the world's population live in urban areas and rest of them live in rural areas. Energy consumption in residential buildings is a significant component of global energy use, contributing to both energy demand and greenhouse gas emissions. Wefki, Khallaf [3] stated that the design, buildings architectural plans, Heating Ventilating Air Conditioning (HVAC) system, thermal conductivity of materials, and using insulated materials significantly affect their energy efficiency. For instance, the use of low thermal conductivity materials can reduce heat transfer and lower heating and cooling needs. One of the important contributor in the production of gases that affects global warming is human activities [4]. Energy usage is predicted to grow at 3% and 0.9% annually in developing and developed countries respectively [5]. Burning fossil fuels in Iraq is a major cause of air pollution, harming both the environment and people's health. According to the World Bank, Iraq's carbon dioxide emissions have more than doubled over the past two decades, increasing from 85 million tons in 2000 to 180 million tons in 2020. This rise is largely driven by the country's growing electricity production [6]. The residential sector is the biggest consumer of electricity, accounting for about 50% of total usage. Building materials play a significant role in greenhouse gas emissions. In Iraq, insulation materials are optional, and most residential buildings are built with traditional materials like brick, concrete blocks, reinforced concrete, and tiles all of which have high thermal conductivity. Moreover, factors like building design, location, and orientation greatly influence energy consumption. As a result, maintaining thermal comfort in Iraqi houses remains a challenge. Many countries still rely on traditional methods such as 2D-CAD drawings. However, these drawings make it difficult to make early decisions during planning. As a result, conflicts often arise during the design and construction phases since engineers and architects work separately, creating designs in their own offices without real-time collaboration [7]. To address such issues, technology is important to utilize and one of the most important technologies that has global acceptance is Building Information Modeling (BIM). The originality of this study is that BIM is a relatively new technology, and many countries worldwide are adopting it and some even making it mandatory, while the use of BIM in Iraq is rare. Moreover, implementing the BIM methodology is expected to shift the construction industry from traditional 2D-CAD drawings to a more collaborative model-based approach. This change has the potential to improve planning, construction, and management, making processes more efficient, transparent, and environmentally friendly. Therefore, the aim of this study is to make a comparison in terms of energy consumption and heat loss of three different residential houses that are located in rural areas through utilizing Autodesk Revit and Insight 360° which is a cloud-based analysis engine that enables them to go through three sophisticated energy analysis.

2- Building Information Modeling

BIM is regarded as a digital tool that can improve a construction's collaboration, quality, time costs and facilities management [8]. Many organizations in developed countries regard it as one of the primary tools in the construction industry. Unfortunately, BIM has yet to be implemented in the Iraqi construction industry due to several obstacles such as "lack of knowledge", "using traditional methods of contracting", a "lack of BIM awareness, and lack experts" [9]. Globally, public expenditure is responsible for most of the growth in this sector [10]. BIM is an upgrade to Computer Aided Design (CAD) models as it contains the specification of materials, their costs, materials' spatial data, their quantities and more. It is a lot more than just a visualization tool. It enables the definition of relationships and behavior of building elements, doors, windows, columns, slabs and walls. The computerization of construction work promises to improve efficiency and productivity significantly. BIM provides the foundation for the new methodology known as Building Energy Modeling (BEM). By integrating BEM, builders can optimize construction processes, leading to more sustainable and energy-efficient buildings [11, 12]. Over the past decade, the construction industry has undergone significant growth in the adoption of advanced information technology. A major driver of this transformation has been the introduction of BIM, which, despite initial challenges, has reshaped construction methods [13].BIM is a virtual representation of the functional and physical properties of a building, which helps stakeholders in the building lifecycle to collaborate and make good decisions [14]. In energy analysis, BIM allows the connection between the building geometry and corresponding material properties, as well as the systems data and the energy simulation tools [15]. Through this integration, early-stage assessments of energy performance can be performed, and designers can pinpoint and mitigate inefficiencies before they enter the construction phase. A facilitated critical decision-making can be employed using an energy model, which enables architects and engineers to play a key role in shaping building energy use patterns with the application of the technology [16]. Such a method can also help predict the major energy consumption of each specific building. Identifying the major end users allows energy design professionals to target their efforts toward strategies for reducing consumption on the highest consumers [17]. Furthermore, once the geometry and systems of the building, its geographic context, materials, and other elements are set up, the use of BIM tools allows for the integration of all aspects of energy performance analysis [18]. This system, in turn, allows for greater accuracy in energy performance measures, less energy usage, and remarkably reduced costs associated with the operations [19]. Therefore, improving building energy performance is one of the most important substances and should be done in the design phase.

3- Requirements of Thermal Insulation

Many considerations should be considered when designing thermal insulation of buildings such as building envelopes, building geographical locations and thermal resistance of materials (R-value). Building envelopes are crucial for energy efficiency in the construction industry. Poor insulation can lead to significant energy loss, accounting for up to 40% of total dissipation [20]. The building sector is responsible for 40% of total energy consumption and 39% of carbon dioxide emissions. More than 28% are related to the building operation and 11% are related to building materials [21]. To reduce energy use, managing heat exchange and incorporating thermal insulation are essential. This not only cuts costs but also minimizes environmental impact. Therefore, BIM enhances construction quality, reduces risks, and promotes investment in both public and private sectors, benefiting the economy, society, and the environment [22]. Another factor that affects thermal insulation is the location of the building. Human activity, especially fossil fuel use, has significantly influenced climate change, leading to rising global temperatures, with projections of a 2°C increase by

2035 and potentially over 5°C in the future [23]. According to Moamin Al-Kakaei, Ayesha Aljuboory [24] Iraq's climate has become increasingly extreme due to fossil fuel consumption, shifting from periods of cooling to prolonged and intense heating. This shift directly impacts on workers' health, productivity, and income, making sustainable building practices essential for climate adaptation. Wind conditions also influence thermal insulation performance. Higher wind speeds reducing resistance and potentially causing air leaks. Proper building design that considers wind direction can enhance natural ventilation, improving energy efficiency and indoor comfort [25, 26]. Additionally, humidity influences energy performance, as humidity-sensitive ventilation systems and moisture control in structures can contribute to energy savings.A final factor influencing heat loss is the R-value of materials. The "R-value" measures the thermal resistance of any material or component indicating how well it prevents heat transfer [27]. A higher R-value means the material has significant insulation and better energy efficiency. This indicates that the use of such materials will result in reduced energy loss through the building envelopes, ultimately lowering overall energy consumption.

4- Materials and Methods

The present study involves a case analysis of three actual residential houses located in rural areas in Duhok governorate. Each one is built with different building materials as shown in the table (1). As is known, Autodesk Revit and Insight 360° software are widely used for the energy analysis. The 3D BIM model of each house is created using Revit. To accurately simulate energy conditions, Autodesk Revit requires data on various physical building parameters that influence the energy use intensity of a residential building. The following steps are carried out to generate a 3D BIM model. Gathering appropriate data for case studies, such as material used and 2D-CAD drawings. Then transferring this drawing to a 3D model using Revit. Figure (1) shows the 2D-CAD plane and 3D model for the case study. Defining the materials used (walls, slab, roof, floor, doors and windows) for each house and specifying their thermal properties according to [28] thus they could be representative of the Iraqi context. This involved specifying the materials' heat transfer coefficients (U-values) and density to ensure accurate energy analysis. Table (2) below shows the thermal conductivity of most materials used in Iraqi market. The energy model's behavior is guided by its settings, which also control the inclusion of extra Revit model details like materials and thermal attributes. Thermal properties for building elements are defined in the Building Energy Modeling (BEM) process. The model uses Revit-generated data for components like walls and windows. Parameters such as building type, schedule, and HVAC settings are configured, affecting the energy analysis and the building's heating and cooling loads. After energy settings were set up, the next step was creating spaces and zones within the model to represent thermal and functional areas. Defining location as shown in figure (2) and ensuring weather station data using internet mapping services and the closest weather station to the case studies was selected. In addition, prior to starting energy simulation, the weather data of the selected station were checked by gaining weather data of ten years as shown in figure (3). After the location is defined the next step was creating energy models and checking the accuracy visualization of the model generated as shown in figure (4). Once the model is validated, then it is exported to Insight 360°, where advanced energy performance analysis is conducted. Insight 360° allows designers to explore and optimize energy performance by adjusting variables such as orientation, Wall-to-Window Ratio (WWR), materials, HVAC systems, infiltration, light efficiency and operational parameters. The flowchart in figure (5) illustrates a systematic process for performing energy analysis using Revit and Insight 360°. The process begins with creating a 3D BIM model using AutoCAD drawings for the case study. Key building information, such as building type, operation schedules, and HVAC configurations, is then inputted. Spaces and zones are defined as representing thermal and functional areas, and the model is checked for errors or unclosed spaces, which are corrected as needed. Once validated, the building's geographic location is set to incorporate climate and weather data. An energy analytical model is then generated and its accuracy visualized. The model is exported to Insight 360° for advanced energy performance analysis. The process concludes with an optimized design that ensures energy efficiency and sustainability.

5- Results and Discussion

Building materials play a key role in energy consumption. It is possible to reduce energy usage in buildings by employing effective technologies such as using insulating materials. In this study, three different residential buildings that are located in rural areas were studied. Energy consumption is calculated using Autodesk Revit and Insight 360°. The building's energy use of the case studies is calculated on the basis of Energy Use Intensity (EUI) in kWh/m^2 per year. The construction of walls and roofs is of vital importance in mitigating the energy consumption of a building. Materials used in the wall and roof slab have significant effects on the energy losses were using insolated materials leads to limiting heat losses and gains. The shape, material, exterior surface color, and size of the wall and roof can affect the thermal performance of the building. Therefore, walls and roof slabs must be constructed to accommodate a variety of weather conditions. Each type of wall and roof construction provided has its own thermal resistance and heat capacity. In house (01), the construction of the wall is 470 mm thick and consists of concrete block, insulation layer (cork), concrete block, gypsum plaster from inside, and cement-sand plaster from outside. The roof slab is made of reinforced concrete approximately 150 mm thick with no insulation. In house (02), the thickness of external walls is 240 mm and consists of cement-sand plaster from outside, concrete block as a main layer and gypsum plaster from inside. The roof slab of this house is 280 mm thick and made of three layers which are reinforced concrete, insulation layer and concrete. In house (03), the wall constructed is 240 mm as in house (02), while the roof slab is 150 mm as in house (01). The thickness, thermal resistance (R-value) and overall heat transfer coefficient (U-value) of each material incorporated into the wall and roof assemblies are presented in table (3), providing a detailed overview of the thermal properties used in the analysis. After the energy analysis is conducted, the mean Energy Use Intensity (EUI) in house (01), house (02) and house (03) are 145, 162 and 170 kWh/m2/year respectively as shown in figure (6). The results showed that insulating walls using cork material consumes less energy following that insulating only roof slabs also leads to reduce energy consumption. This is due to the fact that each of the roof slab and wall represent about 25% - 30% of the area exposed to external heat, this means insulating either walls or roof slab helps to reduce energy consumption. However, to obtain better energy consumption, it is preferable to insulate all the components that are exposed to external heat. Therefore, stakeholders should consider this point when they are designing buildings. As a part of the study, a thermometer is used to find out the heat loss in the selected case studies and compared with results obtained from Revit and Insight 360°. In each house three thermometers were used, and the mean temperature was recorded using time interval of 10 – 15 min for each record as shown in the figures (7,8,9). In each house, a heat system was equipped to warm the interior. The maximum indoor temperature was recorded. After the heating system was switched off, the temperature was monitored and documented at regular intervals for the duration specified. The maximum temperature reached up to 25.5 °C, 24.1 °C and 21.1 °C for house (01), house (02) and house (03) respectively.The graphs show how temperature inside house (01), house (02) and house (03) decrease over time, apparently after the heating system is turned off. It spans a period of 315 minutes, with temperature dropping in each house. As can be seen, in each house there is heat loss over time. House (01) demonstrates the most effective thermal performance among the three. The temperature starts at approximately 25.5°C and gradually decreases over time, eventually stabilizing around 11°C after approximately 5 hours. The rate of cooling is initially moderate but slows significantly after the first 90 minutes, indicating that the internal environment retains heat well. This strong thermal resistance is attributed to the use of cavity walls filled with cork insulation, which reduces heat transfer through the walls. Additionally, the solid concrete roof slab contributes to maintaining internal warmth due to its thermal mass. Overall, the combination of insulated walls and a dense concrete roof enable House 01 to retain heat efficiently, making it the most thermally stable design. House (02) begins with an internal temperature of about 24.1°C and cools gradually to around 14.5°C over the same time period. The cooling curve shows a steady decline, slower than House (03) but slightly faster than House (01). The structure consists of solid concrete block walls without insulation and a layered roof that includes insulation between two layers of concrete. The presence of insulation in the roof slows down heat loss from above, contributing to a more stable internal temperature compared to a fully uninsulated design. However, the lack of insulation in the walls allows for more heat escape than in House (01), leading to moderate thermal performance overall. House (03) exhibits the fastest drop in temperature, starting at about 21.1°C and decreasing to roughly 9°C over 315 minutes. The cooling rate is steep during the first hour, indicating rapid heat loss. This behavior is a result of the construction, which includes solid concrete block walls and a solid reinforced concrete roof, both without any insulation. Concrete alone offers limited resistance to heat transfer, and without insulation, the internal heat escapes quickly through both the roof and walls. As a result, house (03) performs poorly in maintaining thermal comfort and is the least energy efficient among the three houses. As a summary, table (3) shows the comparative summary of the selected case studies.

The relationship between decrease in temperature overtime was modeled. The equations in the graphs are as follows:

$$y = 20.531e^{-0.001x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$y = 20.103e^{-0.002x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$y = 17.911e^{-0.002x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

This is an exponential decay function, where:

y is the temperature in °C

e is Euler's number

x is time in minutes

Table (5) below shows the comparison between the three equations. Equations (2 and 3) decay at the same rate (−0.002), that is, they have identical cooling rates. However, equation (2) starts at a temperature that is hotter than equation (3) and thus will always be above it. Equation (1) on the other hand has a much lower decay rate (−0.001), thus it is cooling at a slow rate than both equations (2) and (3) even though it starts off with a similar temperature to Equation (2). This means the temperature in house (01) keeps heat longer compared to the others. Overall, while houses (02) and (03) show the same rate of temperature drop, house (01) stands out for its slower cooling behavior, making it the least responsive to temperature change over time. It should be noted that the initial values y_0 reported in table (5) (20.531, 20.103, 17.911) are extrapolated temperatures at $t = 0$ based on the curve fits, rather than the actual measured maximum indoor temperatures. While this provides a consistent baseline for comparing the cooling behavior of the different houses, the slight discrepancy from measured values should be considered when interpreting the results. As can be seen, both BIM simulation results and temperature experimental align because they both reflect how different construction materials and insulation strategies affect a building's thermal performance, and ultimately, its energy consumption, as well as they governed by the same physical principles of the heat transfer through building envelopes. Insulation slows this transfer down, which reduces energy demands for maintaining indoor comfort. The BIM software models this using thermal properties of the materials and simulates how much energy is required, while experiment observed the same outcome through real-time temperature change.

6- Conclusion

This study highlighted the impact of construction material selection on energy consumption in rural residential buildings. By correlating BIM-based energy analysis with experimental temperature measurements, the research demonstrated a high level of accuracy in predictive modeling, validating the use of BIM tools for this context.

The results showed that the BIM analysis aligned closely with the recorded temperature data, validating the software's predictive accuracy see figures (6 to 9). Walls play a vital role in energy consumption. Therefore, using materials with better thermal insulation can significantly reduce energy consumption in rural homes. Adopt BIM tools can optimize energy performance and help monitor sustainability standards from the design phase. While this research focused on rural case studies, future work should expand to urban settings and diverse climate zones to generalize the findings. There is also a significant need to investigate alternative sustainable building materials and integrate BIM with lifecycle cost-benefit analyses. Furthermore, given the limited adoption of BIM in the Iraqi construction sector, future studies must address strategies to overcome implementation barriers in both residential and public projects. Ultimately, the thermal performance data obtained in this study should serve as a foundation for developing clear policy recommendations and practical construction guidelines to enhance sustainability in rural Iraq.

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استهلاك الطاقة في المباني السكنية الواقعة في المناطق
ANSYS تأثير مواد البناء :BIM الريفية من خلال استخدام

المستخلص

يتزايد الاعتراف العالمي بنمذجة معلومات البناء (BIM) كأداة فعّالة تُعزز الإنتاجية في قطاع البناء. فمن خلال تمثيل بيانات البناء رقمياً، يُساعد BIM على تقليل وقت وتكاليف البناء مع تحسين جودة المشروع. تبحث هذه الدراسة في استهلاك الطاقة في المباني السكنية الواقعة في المناطق الريفية بالعراق باستخدام أدوات BIM، وتحديداً Revit و°360 Insight. في هذه الدراسة، تم تحليل ثلاثة منازل مبنية بمواد مختلفة من حيث أدائها في استهلاك الطاقة. قُيّم استهلاك الطاقة باستخدام محاكاة BIM، وقيست درجة الحرارة الداخلية يدوياً على مدار ٣١٥ دقيقة باستخدام موازين الحرارة. أظهرت النتائج أن متوسط كثافة استخدام الطاقة (EUI) للمنزل (٠١) والمنزل (٠٢) والمنزل (٠٣) بلغ ١٤٥ و١٦٢ و١٧٠ كيلوواط ساعة/متر مربع/سنة، على التوالي. تطابقت نتائج المحاكاة هذه بشكل وثيق مع بيانات درجة الحرارة المسجلة من حيث فقدان الطاقة، مما يدعم دقة تنبؤات البرنامج. بناءً على هذه النتائج، يُوصى بأن تُعطي مشاريع البناء الريفية الأولوية للمواد ذات العزل الحراري الأفضل لتقليل استهلاك الطاقة بشكل كبير.

الكلمات المفتاحية:

BIM، استهلاك الطاقة، المناطق الريفية، مواد البناء

Table (1) Materials used in case studies

Category	Building 1	Building 2	Building 3
Wall	Cavity wall	Concrete block wall	Concrete block wall
Facade material	Cement-sand plaster	Cement-sand plaster	Cement-sand plaster
Interior material	Gypsum	Gypsum	Gypsum
Roof	Solid reinforced concrete	Solid reinforced concrete with insulation	Solid reinforced concrete
Floor	Mortar with tile	Mortar with tile	Mortar with tile
Exterior door	Aluminum	Aluminum	Steel

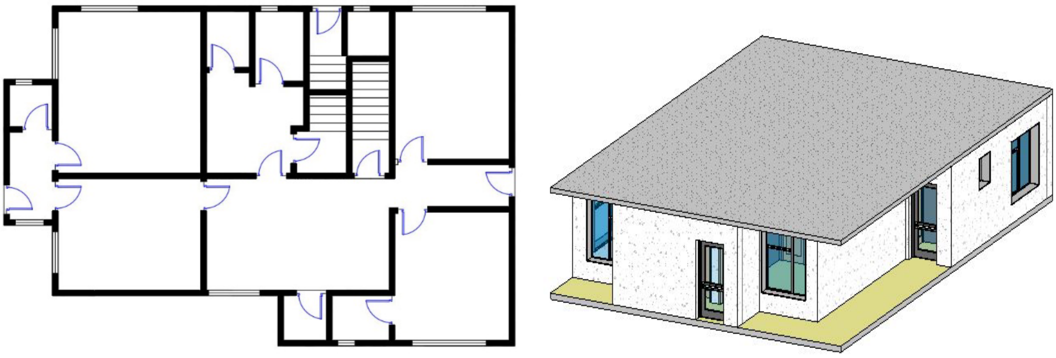

Figure (1) Case study used for energy consumption

Table (2) Thermal conductivity of materials , source: [28]

Item	Material type	Thermal conductivity (W/m.K)
1	Block (Hollow) - 20 cm	0.5
2	Block (Hollow) - 15 cm	0.6
4	Block (Solid)	0.9
5	Brick (Cavity)	0.4
6	Brick (Solid)	0.5
7	Concrete (Reinforced)	2
8	Concrete (Not Reinforced)	0.8
9	Cement plaster	1
10	Granite	3
11	Gypsum	0.2
12	Limestone	1.5
13	Marble	2.2
14	Sandstone	1.5
16	Cork (EPS)	0.05
17	Polystyrene (XPS)	0.08

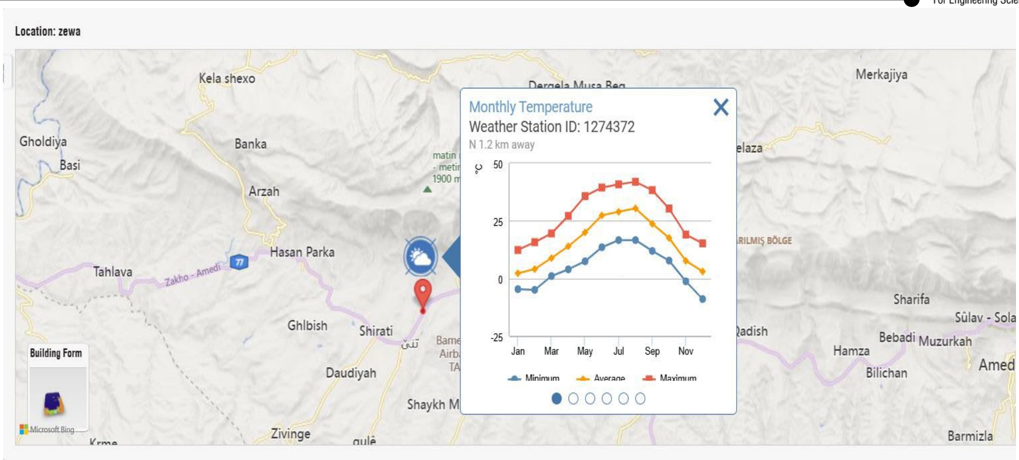

Figure (2) Location of building and weather station

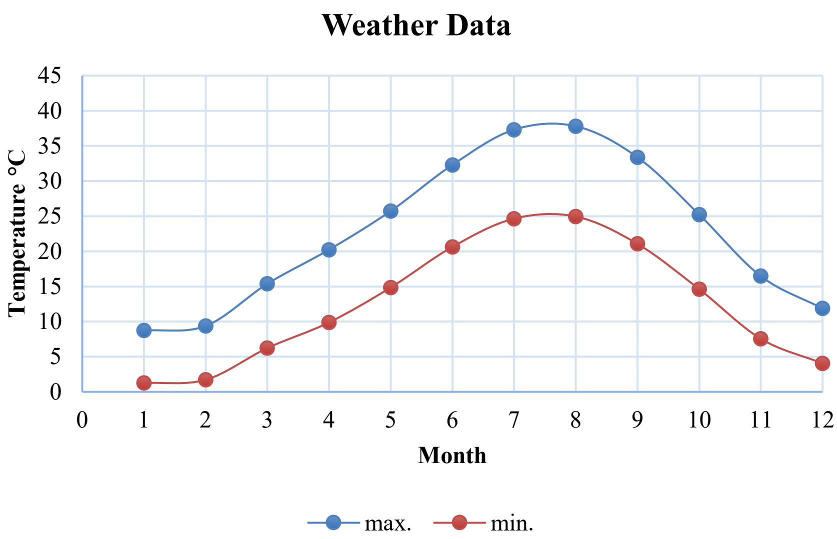

Figure (3) Weather data for Bamarni station

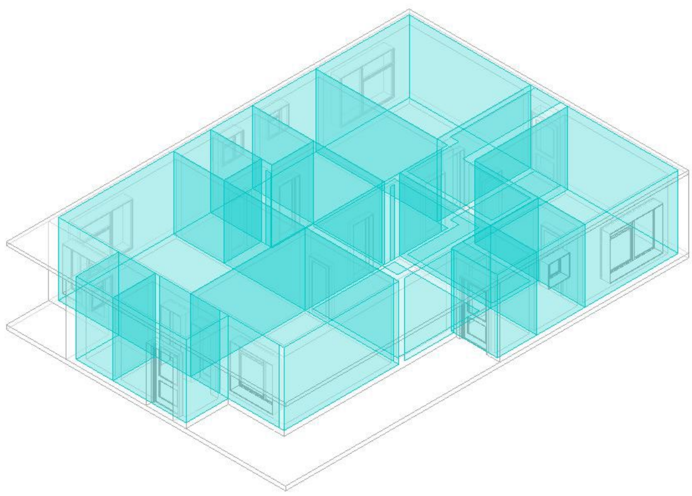

Figure (4) Energy model in Revit

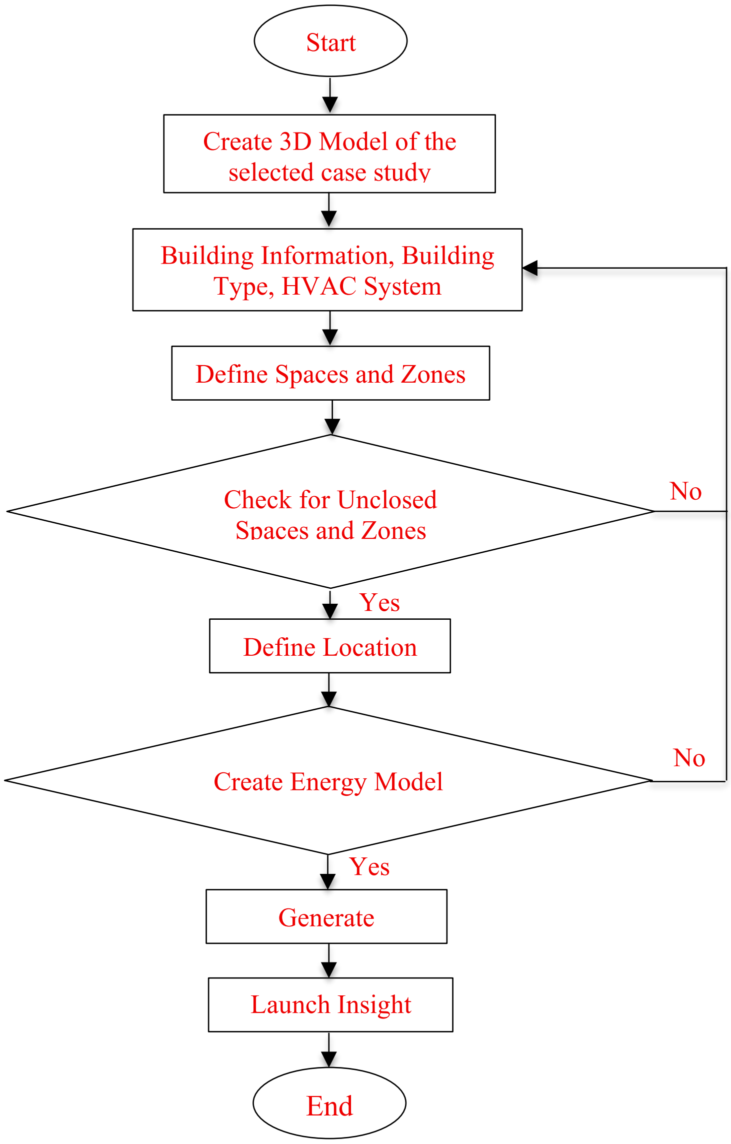

Figure (5) Energy analysis using Revit and Insight 360° flowchart

Table (3) Thickness and analytical properties of materials

House No.	Component	Layers	Total Thickness (cm)	R-value (m^2.K/W)	U-value (W/m^2. K)
01	Wall	Gypsum plaster (inside) (2 cm) + Hollow Concrete block (20 cm) + Insulation (cork) (3 cm) + Hollow Concrete block (20 cm) + Cement-sand plaster (outside) (2 cm)	47	1.6892	0.5920
	Roof slab	Reinforced concrete (no insulation) (15 cm)	15	0.1457	6.8634
02	Wall	Cement-sand plaster (outside) (2 cm) + Concrete block (20 cm) + Gypsum plaster (inside) (2 cm)	24	0.4784	2.0903
	Roof slab	Reinforced concrete (15 cm) + Insulation (3 cm) + Concrete (10 cm)	28	1.1434	0.8745
03	Wall	Cement-sand plaster (outside) (2 cm) + Concrete block (20 cm) + Gypsum plaster (inside) (2 cm)	24	0.4784	2.0902
	Roof slab	Reinforced concrete (no insulation) (15 cm)	15	0.1457	6.8634
The coefficients of convection heat transfer for external and internal surfaces are assumed to be between (10 - 15 W/m^2. K) and (2 - 5 W/m^2. K) respectively.					

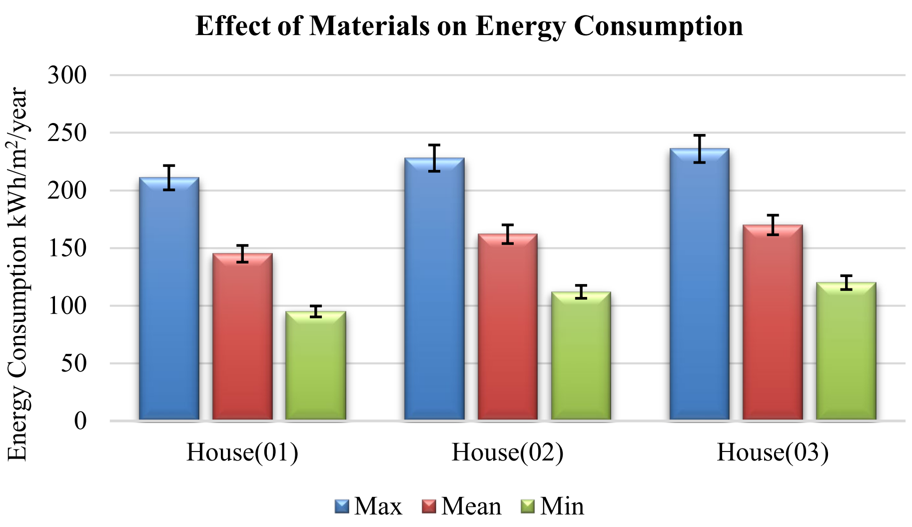

Figure (5) Annual energy consumption in the three houses

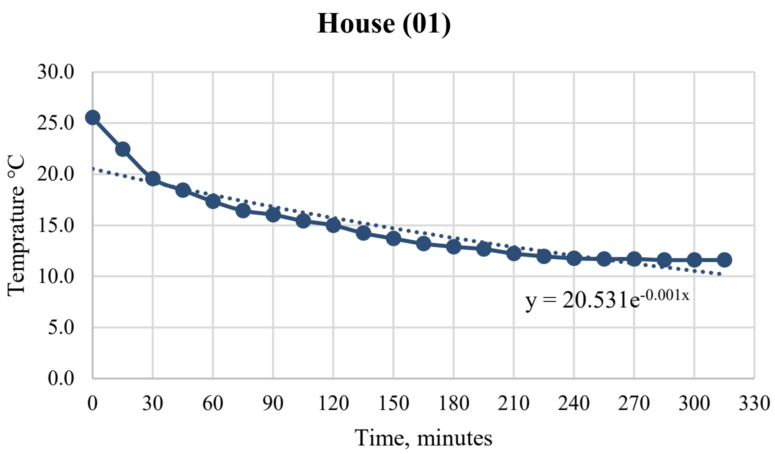

Figure (7) Heat loss in house (01)

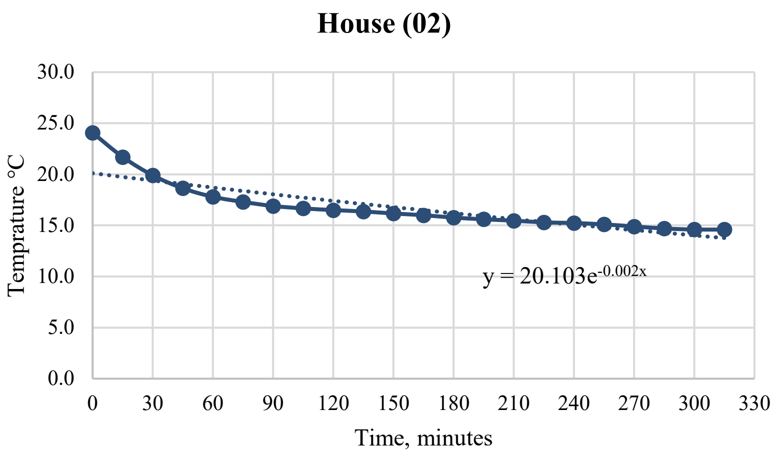

Figure (8) Heat loss in house (02)

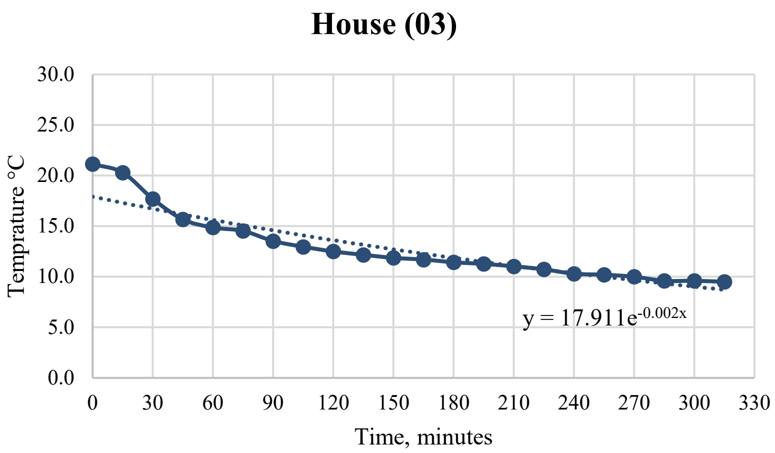

Figure (9) Heat loss in house (03)

Table (4) Summary comparative of case studies

Feature	House (01)	House (02)	House (03)
Wall type	Cavity wall (Insulated)	Solid concrete block	Solid concrete block
Roof	Solid concrete slab	Two concrete layers with insulation between them	Solid reinforced concrete
Insulation part	Wall insulation (cork)	Roof insulation	No insulation
Initial Temperature	25.5°C	24.1°C	21.1°C
Final Temperature	11°C	14.5°C	9°C
Thermal Efficiency	High	Moderate	Low
Cooling Rate	Gradual levels after 3 hours	Steady, slower than house (03)	Rapid, steep early drop

Table (5) Summary comparative between the three equations

Feature	Eq. 1	Eq. 2	Eq.3
Initial value y_0	20.531	20.103	17.911
Decay rate	- 0.001	- 0.002	- 0.002
Decay speed	Slowest	Moderate	Moderate
Starts from	Highest	Middle	Lowest