Environmental and Climate Technologies
2023, vol. 27, no. 1, pp. 407–421
https://doi.org/10.2478/rtuect-2023-0030
https://content.sciendo.com

Evaluating Shading Effects of PV Systems: Discrepancies in Simulation Software and Energy Consumption

Aiman ALBATAYNEH[1*], Renad ALBADAINEH[2]

[1,2]*Energy Engineering Department, School of Natural Resources Engineering and Management, German Jordanian University, Amman, Jordan*

Received 30.01.2023; accepted 24.06.2023

***Abstract* – A critical procedure in sustainable building design is that building energy consumption has significant implications for the global energy crisis and climate change. This study compares three simulation software programs for a photovoltaic system on a building's roof. The low-rise residential buildings in three East Mediterranean cities (Amman, Mafraq, and Aqaba) represent moderate dry–warm, semi-arid, and humid subtropical climate zones were compared using three simulation software programs (IES-VE, Design-Builder, REVIT) for a typical building with PV on the roof and the second scenario without a PV system installed on the roof. This investigation aims to evaluate the shading effect of the PV system on a building's roof structure by calculating the total heating and cooling loads required to maintain thermal comfort inside the building. The results showed significant discrepancies between the three software for the base building design and the PV system on the roof, with a range of around 50 %. This highlights the importance of evaluating and calibrating different simulation tools and using them with a great deal of caution.**

***Keywords* – Buildings simulation; Design-Builder; East Mediterranean; IES-VE; REVIT; PV.**

1. INTRODUCTION

Jordan relies on purchasing gas and oil from other countries due to the shortage of domestic energy resources. According to the Ministry of Energy and Natural Resources [1]. According to official data, the Kingdom imports more than 95 % of its energy needs [2]. Due to the fast population expansion of about 3.6 % annually and the rise in industrial processes, yearly energy usage has quickly grown in recent years, resulting in environmental degradation and financial crises [3].

Through the years, the electrical consumption for Residential and public buildings has increased, causing the highest sector to consume energy. The "End-user" is the prime concern in deploying PV technology in housing units' design. It is critical to maintain the setup within the user's budgetary means. As a result, the user's financial capabilities dictate which option is excellent in protecting the PV surface area panel selection, innovation, and performance [4].

Jordan is one of the least developed countries in terms of fossil fuel sources, but it is a suitable location for renewable energy resources such as sun and wind; due to the 300 sunny

* Corresponding author.
E-mail address: Aiman.Albatayneh@gju.edu.jo

©2023 Author(s). This is an open access article licensed under the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0).

days per year, the wind is available daily in many sites. Proper, long-term waste management is critical for preserving and guaranteeing people's health and the environment [5].

Switching to a paradigm that includes renewable technology would help alleviate those drawbacks by supporting more environmentally friendly methods and strengthening countries' economic and social development. Considering these benefits, altering the model is difficult as the existing non-renewable energy technologies are well-established choices with a lengthy enhancement history, as opposed to the more newly invented renewable energy options [6].

Renewable energy was first used on a limited basis in Jordan 20 years ago to power water pumps and provide lights in remote areas; nevertheless, it was only recently adopted as a large-scale initiative. It occurs when the government permits the linking of minor systems to the primary electrical circuit; as a result, the storage cost, which accounts for nearly 40 % of the overall amount, is minimized [7]. PV technologies are widely installed in private residences, schools, institutions, healthcare facilities, and mosques. Many individuals can also sell electricity to the public utility commission [8]. Homeowners are encouraged by the state for one-third of the overall price, and financial institutions are helping them through monthly system payments with no added expenses or loans. For Jordan and other underdeveloped nations, clean energy is the optimum clean and renewable energy, particularly the photovoltaic system. This energy is surfacing worldwide, including in Jordan, where plenty of minor and significant initiatives have already been erected and will come to a halt in the coming years [5].

Thermal analysis is now a widely used tool to forecast the thermal performance of facilities. The recent few generations have seen the emergence of many technologies, most of which were independently validated while considering various operating situations [9]. This research aims to compare the simulated results for the baseline model and its improved version to assess the differences between using the most widely used building performance simulation tools, IES-VE, Design-Builder, and Revit. Solar radiation hits the building on its external surface as the walls and roof present the external shell of a building. The roof absorbs most of the solar radiation incidents in the building. Sometimes, it reaches one kW/m² in the clear sky; the solar radiation varies depending on the location of the building, the tilt angle of the sun, and the climate condition for each season. In designing a residential dwelling, the roof is a primary element in the design process as it shapes the masses. It found many solutions for reducing heat through the roof: applying shades, stepped roofs, insulation materials, the roof thickness, and construction water pools on the roof. Also, double-skin domed roofs provided roof shades of classic Middle Eastern buildings [9].

The roof design is a critical element in determining energy consumption by the building as it is connected to the phenomena of heating and cooling loads, occupant welfare, and urban heat islands. Research stated multiple types of roofing systems but mentioned that those systems are still in the process of becoming consolidated from a technical and financial standpoint, as they demand a high level of technical skill to design, implement, and maintain, as well as significant expenditures. So, their research focused on the effect of inclination and orientation as an essential element to optimize the roof thermal dynamic behavior about the environmental targets considering the outdoor and indoor climatic conditions of lightweight and traditional heavyweight roofs. As a result, the external surface temperature depends on roof orientation, while internal surface fluctuations depend on roof typology. Regardless of the roof configuration or location, the East-facing roofs have the lowest decrement factor values, followed by the South, West, and North-facing roofs. Changing the inclination and azimuth angle for a particular roof typology revealed a width decrement factor variance [10].

Furthermore, Roofing techniques are mentioned and implemented widely; there are concrete roofs, cool roofs, roof gardens, insulated roofs, photovoltaic panels roofs, bio solar roofs, double-skin roofs, roof ponds, and skylight roofs. Also, another study clarified that each material has its thermal properties that specify the absorbed, reflected, and transmitted solar radiation. In addition, in roof-overhang design systems, terracotta-made roof tiles also protect inhabitants from excessive solar radiation in the summer, and roof surface material is observed to affect the indoor comfort of occupants more than the increase in the roof thickness. To conclude, the materials chosen for roof surfaces have a greater impact on indoor temperatures, followed by the thickness of the thermal mass and the building height [11].

To insulate the roof, there are many ways to protect the roof's surface from external solar radiation entering the internal surface of the roof structure; one way to reduce heat gain and loss from the roof's external shell is to insulate the existing roof thermally by using polyurethane foam insulation as indicated in the simulation retrofit process for an existing building in Saudi Arabia; the polyurethane foam was used to enhance the thermal performance and resulted in reducing the U-value from 2.123 W/m².K to a value of 0.131 W/m².K which reduces in minimizing roof usage by 18.4 % on an annual basis. It is critical to mention that the smaller the U-value of the insulation composition, the greater the insulation will be in terms of thermal performance, resulting in more significant energy savings [12].

It is crucial to remember that the cut down in energy consumption can be accomplished by retrofitting the building envelope from the demand and supply sides. To achieve the optimum building envelope with low energy consumption, various retrofitting and energy-saving approaches have been evaluated and compared in a non-residential building. On the consumer side, energy efficiency can be obtained by renovating the building envelope with improved building material in the roofs, walls, glass, and shading systems, as well as by utilizing daylighting and natural ventilation. Planting the roof and adding 50 mm roof insulation with a thermal conductivity of 0.049 W/(mK) were incorporated into the roof structure for the possibility of annual energy savings. The proposed roof design has a U-value of 0.424 W/m². K is significantly lower than the basic case U-value of 1.743 W/(m²K) [13].

Furthermore, phase change material is one of the techniques used to minimize heat transfer through the roof. Phase change material was implemented in two scenarios to account for the weather conditions in Riyadh; in the first scenario, the phase change material is treated as a substance that has no phase change, whereas in the second case, the phase change material in the walls and roof have phase change. The internal temperatures were set to 23 °C and 25 °C in the winter and summer, respectively, and phase change material thermal performance was assessed monthly and annually. The findings revealed that the inside temperature considerably impacts the thermal behavior of a phase change material-equipped structure. Due to its good performance, the phase change material significantly decreased heat transmission in the winter, when the temperature was set at 23 °C. As a result, engineers should exercise extreme caution when selecting a phase change material, as it may function admirably in the winter but have little effect in the summer. Due to the weather conditions in Riyadh and setpoint temperatures of 25 °C for summer, it was discovered that adding phase change material of RT-23 seems not to influence July, August, or September. However, due to this material's outstanding performance in the remaining months, the yearly heat exchange from the roof was decreased by 35 % [14].

Another three substances were evaluated in Mediterranean climates: polystyrene, rock wool, and fine white sand, with heat-lowering values of 58.5 %, 38.01 %, and 62 %, correspondingly [15]. They were examined on hot days, implying that they have the same impacts in hot environments. When encapsulation is combined with other approaches like

ventilation or a reflecting coating, its performance can rise to 84 % and 88 %, respectively [16].

IES Virtual Environment (VE) software is one of the used programs. A comparison of several simulation tools identified IES-VE as one of the most influential and productive simulation tools assisting engineers in evaluating diverse construction systems [17].

The IES-VE program analyzes the thermal behavior of the structure based on the APACHE simulation engine and investigates the thermal performance of the residential house as a baseline model without PV system integration as a shading device and with PV system integration as a shading device. The values of simulation parameters – lighting, occupant number, heating setpoint, and cooling setpoint – were input according to the function of each space in the most suitable conditions for the constructed model. IES-VE permits a quick comparison with the performance of comparable models and the production of instantaneous and precise findings, making it a convenient and user-friendly technique for analyzing and optimizing a building's envelope and surroundings. IES-VE allows users to investigate how adjusting specific materials in the building fabric affects the energy efficiency and usage of the structure [18].

This is due to its well-established popularity and comprehensive utilization among investigators, educators, architects, and engineers as an integrated energy assessment platform for the formation and renovation of dwellings. It is known for transforming complicated thermal arithmetic operations into easy-to-understand technical specifications and modeling [19].

IES–VE can be used as a data planning instrument. This implies that it is simple to grasp. Because architects recommend rapidly generated visualized information and outputs over quantitative schedules, the software can declare data and outputs with infographics. The information handling capacity of the application is the other major issue to consider. It meets the demand for fast and precise evaluations for many options while also ensuring the nature of simulation results. The program allows easy access and enhancement in the measurement of thermodynamic performance, enabling rapid replies at the beginning of the design phase and an analytical approach in the subsequent stages of design. Throughout the last 50 years, the IES-VE's simulation program has been enhanced and upgraded. A comprehensive behavior tool with integrated capabilities is included in this application. As a result, the software can sustain extensive thermal and natural lighting data and conduct other ecological evaluations. Because the finished design process and environmental data analysis are visually attractive and have a broad set of performance analytical techniques encompassing solar, energy, and lighting data, time and money, egress, computer modeling, and mechanical measurements, it is well-suited to the objectives of this paper. IES-VE is composed of numerous elements [20].

Design-Builder is the second computational program that was used in this research. Design-Builder is nearly one of the tools architects and engineers praised and rated among the best. It is designed to execute Energy Plus calculations on digital solid modeling. It is used in this software to mimic heat transfer procedures, climatic factors, and other elements that affect energy usage in structures. The Energy-Plus is the simulation engine integrated into the Design-Builder software and provides several features, including modeling, assessment, improvement, and environmental effect analysis [21].

Moreover, Energy-plus is a whole-building energy modeling application used by researchers and experts in the construction sector to estimate energy usage for heating, cooling, ventilation, lighting, and plug and process loads, as well as water consumption in structures [22].

The reliability and appropriateness of database software have been highlighted, particularly in structure performance investigations [12]. Moreover, it is a three-dimensional, all-encompassing platform created on the foundation of Energy Plus. Energy Plus is designed to be a precise computation engine, leaving the creation of more user-friendly pre-and post-processing stages to other tools [23].

The interior and exterior of the residence and the substances utilized in its design were all recreated using Design-Builder to create the final product. By multiplying the design parameters at specified circumstances for an unsteady factor 1, the simulation product's hourly schedules for each thermal zone enable us to examine the hourly amounts of load volume of equipment, lighting, and DWW needed in a year. Because Design-Builder software has rich data forms for a wide range of building simulation entries, such as conventional envelope building components, lighting fixtures, and occupancy schedules, it is ideal for building simulations. These frameworks appeal to newcomers who may not recognize when more precise inputs relevant to their building are required [24].

Revit software is the third software that was used in this investigation, and it was used for modeling the structure and for solar analysis. Revit is a BIM software that assists engineers, architects, MEP engineers, and constructors with building information modeling [25]. Architects use Revit to generate architectural models, as shown in Fig. 24. This technology has slowly evolved from CAD (computer-aided design) to BIM over the previous decade [26]. It enables customers to create a 3D model of the structure and its elements, annotate the model with 2D drawing elements, and acquire building information from the construction project database. Revit is ingenious enough to plan and monitor all phases of the lifecycle of the building, from design to construction and deconstruction. Among the characteristics of Revit are parametric elements, job sharing, design considerations, set schedules, archiving, project sequencing, accessibility, connected file performance, work in perspective views, and enhanced connection between Revit and structural analysis tools [25].

A three-dimensional Revit model was used to depict the gathered information needed to complete the computation. This prepares the building elements to be tangible and rational, which aids architects and users in making the best strategic choices. All layers of external walls, rooftops, and floors can be inserted to be like the building information to achieve the most significant outcomes. Furthermore, the structure's depiction of a house's spatial location and orientation gives consumers ideas for shading, sustenance, and gardening. The peak cooling and heating demands, the capabilities of devices required to adjust the designated construction, the shares of each element of the facility, including the roof, walls, windows, skylight, ventilation, and infiltration, and the expense of conditioning loads become simple to specify. This aids architects in understanding how parts of the building lose energy and which elements are the largest consumers of energy [27].

Some of the techniques required to alter the construction sector are currently in use, are reasonably priced, and have payback periods of under five years. Building Performance Simulation (BPS) tools, which have emerged as a prerequisite in assessing building energy consumption and thermal comfort, are typically used to determine the possibilities of these innovations. Concerning brand-new constructions, they permit customers to create the envelope appropriately. At the same time, in the scenario of existing structures, significant renovations enable users to select the best solutions to lower energy requirements and enhance indoor thermal comfort. The Integrated Environmental Solutions Virtual Environment, Design-Builder, and Revit are the three simulation programs used in this research to evaluate the energy use of a typical housing unit in Jordan before and after the installation of solar panels in terms of testing their shading effect. The investigation examined how a photovoltaic system could be used to shade a housing unit, which is a traditional

Jordanian residence requires approximately 50,000 kWh annually for a rectangular shape model with an area of 200 m² [28], [29], while the Green Building Council [29] estimates that the yearly primary energy usage by a standard flat in Jordan is 91.4 kWh/m².

Furthermore, the investigation of conventional Marka-Jordan apartments with an area of 110 m² revealed that the yearly energy usage was between these two quantities: 120–140 kWh/m² [30]. This validates the energy consumption rates of our research as they are almost the same built area.

This approach includes evaluating the identical buildings in the three main climate zones mentioned previously in three cities in Jordan, Amman, Mafraq, and Aqaba city, to investigate the shading effect of solar panels by using three simulation programs, which is the main aim of this research; comparing the three software and assesses the differences in using the three simulation programs in terms of the same models and inputs., as this analysis verifies the outcomes of each simulation program. The importance of using three computational programs, especially in building thermal performance evaluation, lies in helping Architects, Engineers, and stakeholders in designing and deciding which route could help in designing sustainable greenhouses, as the global building sector is one of the biggest energy consumers. Weather data was a major issue in dealing with three different software, but in our research, we have clarified how to deal with different weather data to get the same inputs as this is one of our research questions, and the other question that has been answered in this investigation is the importance of using three simulation programs and the difference between using each one of them when dealing with the same inputs.

This research is one of its kind in the Middle East region, as few studies have studied the effect of the photovoltaic system as a shading device for conventional uninsulated roofs in Europe, the United States of America, and Asia. The previous studies included the effect of PV on other types of roofs, and that's what makes this research unique in its field. Also, this study covers a research gap that misses the indirect effect of solar panels on the roof. The investigation of the shading effect of uninsulated roofs will encourage people to install a Photovoltaic system on their roofs due to its double effect in generating electricity and shading the roof. Furthermore, it will reduce the cooling load, enhance the impact of the building sector on the environment, and minimize energy consumption rates.

The findings showed the characteristics of each program while dealing with each one individually. Finally, the evaluation of the results is explained by the differences in each software, such as the weather data files, which is a primary point of consideration.

2. METHODOLOGY

2.1. Model architectural specifications and characteristics

A typical residential building model has been created by Revit software to facilitate the implementation of the energy modeling applications examined in this work, as shown in Fig. 1. It is anticipated that the building area will be approximately 180 m² overall. The long axis of the building faces the south, and it is assumed that there is no shade from the outside or elements that block the sun from entering the house.

The construction layers of the main building envelope elements are stone, brick blocks, concrete, thermal insulation, and interior plastering make up the walls with a total U-value of 0.2800 W/m². K, roof element consists of the following materials: high-strength concrete screed sand and gravel lightweight concrete asphalt roofing bitumen layers plasterboard with a total value of 2.0419 W/m². Floor construction layers are reinforced concrete gravel and soil layer screed ceramic flooring with a total U-value of 1.2827 W/(m²K) [31]. This model is utilized by the energy

simulation programs to generate the building's energy simulation models, which are then evaluated against a set of design criteria and operational conditions. Table 1 presents the comparing findings.

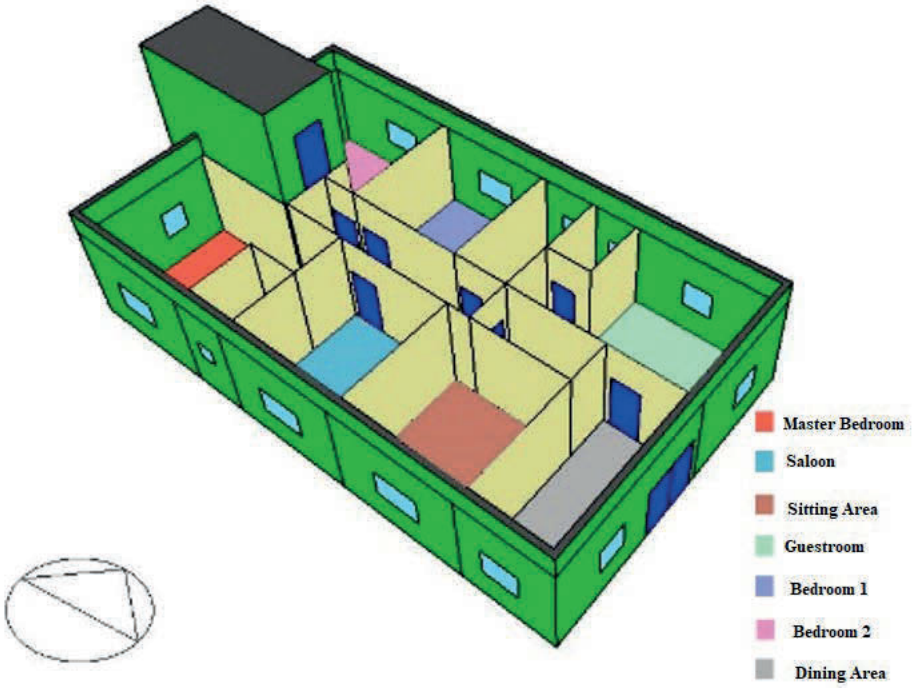


Fig. 1. Three-dimensional view of the baseline and simulated models with their functions.

The same building with the same environmental conditions and surroundings, a similar simulation time, comparable simulation settings, such as time base and simulation algorithm, comparable computer hardware specifications, and comparable software settings are all necessary for conducting an objective comparison of various simulation programs. The criteria used to evaluate how well various simulation applications perform based on (1) the building geometry characteristics, (2) the application's user interface, (3) the capability of the application to import/export data from/to other applications, (4) the accuracy of the simulation results, documentation, and user support.

2.2. The Modelling steps for the PV Panels as shading elements in each of the three simulation programs

PV panels were constructed in each software with a different method; as for the IES-VE program, Topographical shading was used, and for the Design-Builder, the extrusion surface was used to build PV panels, while in the last software (REVIT) PV system was built using roof element with defining one boundary with a slope that is determined by each city (tilt angle) as anticipated in Fig. 2. The chosen strategy for lowering the uninsulated roof's loss impact was evaluated using various design inclination angles while considering the ideal tilt angle for each climate zone regarding the PV panels' capacity to produce electricity. The appropriate performance importance of each approach in examining each climate zone is assessed by building computing programs. By incorporating Solar panels, an efficient method

was used to improve the poorly insulated roof's thermal efficiency. The PV panels incorporated with the structure were created using monocrystalline silicon, a panel characteristic readily available in the region. Also, the input layers of the solar panel are used from reliable research as input in the simulation software [32]. The dimensions were taken as the minimal Solar panels' dimensions in line with the specifications on the Website [33] using clean energy reviews as a source to figure out the dimensions of the PV panels; the panel size that was used in our research is 1 m × 1.7 m with a power output of 300–360 W per panel.

An assessment was made on our experimental base case that has an area of 180 m²; twelve solar panels with an area of 1.7 m² for each panel that produces 300–360 W can roughly fulfill the necessary energy usage of the base case using the earlier research that is situated in the same study area. The system serves as a shading tool. This was used to effectively assess and choose design options that improve the design variable's thermal efficiency.

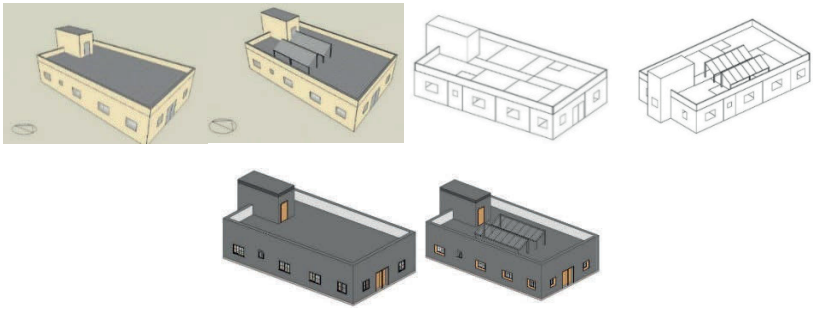


Fig. 2. The baseline model and the simulated model in the three used simulation programs before and after the installation of the PV system.

2.3. Simulation Programs Comparison

Various building energy simulation systems are extensively utilized to estimate a building's energy equilibrium in energy rehabilitation for existing structures or new building construction. Each tool has its own set of advantages and disadvantages for various settings. Furthermore, the residential sector has considerable energy savings potential compared to the manufacturing, transportation, and electricity production sectors. Various Building Energy Simulation software is frequently used to evaluate the energy-saving possibilities of structures (BEMPs). When predicting prospective energy savings from multiple aspects, the reliability of the programs is critical, as it relies on the program's ability to recognize actual heat flow in structures. Various static and dynamic energy simulation software may be used to assess the building transfer of energy, and numerous tools have been commercially released in recent decades [34]. In this research, the simulation process was done by three computational software: integrated environmental solution -virtual solution program, Design-Builder, and Revit and green building studio. The abilities and results of IES-VE, Design-Builder, and Revit are compared in this study. The methods explore how critical factors and heat balance outcomes alter when modeling space heating demand under Aqaba, Amman, and Mafraq weather conditions. The examined structure is tested in Jordan's three climate zones: Amman, Mafraq, and Aqaba. All four computational models for the defined building were simulated monthly using the same or similar criteria and conditions.

The thermal assessment of buildings can face significant challenges, such as using energy instead of temperature, long simulation time, discrepancies in the peak temperature, sky

temperature and wind assessment, infiltration, and occupant interaction with their environment [35]–[42]. Furthermore, external influences may affect the energy cost and PV energy generation, such as subsidies, dust impact, and recycling at the end of the PV lifetime [43]–[45].

2.4. Energy Simulation Tools Comparison Criteria

Each simulation tool has its advantages and disadvantages; the user determines which computational tool suits his project depending on knowing the specific characteristics of each program. Dealing with simulation programs requires experience and practice in using each one. The audience of any simulation software is determined by the services each program provides, as choosing the appropriate simulation tool is specified by matching its capabilities with project requirements, having enough precision to anticipate energy consumption and compliance with ASHRAE standards. in the field of energy engineering, it is clear that the most used and standard simulation software were IES-VE, Design-Builder, and green building studio [46]. Simulation programs mainly contain three primary components: input variables, system parameters, and output [47]. The environmentally friendly interface of the three programs includes the usability category, divided into input and output data representation, ease of use and navigation, and three-dimensional figures of the outcomes. In all testing techniques, the computations depend on the hourly time steps. For each constructed model, the ground temperature is 13 °C. Factors like hot liquid flow, lamps, and electrical equipment cause all models' internal heat gains. In the winter and summer, the predefined indoor temperatures are 20 and 26 °C, correspondingly.

2.5. Comparison Criteria of the three programs according to their inputs

TABLE 1. COMPARISON BETWEEN THE THREE PROGRAMS

Point of comparison	**IES-VE**	**Design-Builder**	**Revit**
Major potentials	Whole building energy simulation, Lighting calculations, Load calculations, HVAC system-wide range of selections	Whole building energy simulation, Parametric and optimization, Load calculations, HVAC system-wide range of selections, daylighting capabilities using Radiance	Revit is highly sophisticated and capable of automatically generating three-dimensional (3D) models from two-dimensional (2D) drawings, Sustainable Processes, and Energy Efficiency (GBS)
API language	Python	C#, Python	NET API (includes all programming languages); (C#, VB.NET, F#, etc.)
Input and output file formats and data.	Input: BIM, SHP, and GML files. Output:gbXML, DxF 2D and 3D, STL, and GEM file formats	Input: IDF, DXF, PDF, BMP, JPG, GIF, TIFF. Output:gbXML, DxF 2D and 3D, XML, MagiCAD	Input: CAD formats, PDF, IFC, Revit files,gbXML, and Images. Output:gbXML, CAD formats(DxF 2D and 3D, DWG, DGN, and ACIS), FBX, IFC, DWF/DWFx, and Images
Geometry and modeling features	The model created a 10 % increase in the space volume and area as the calculation method is based on the center lines of the walls.	The software did not provide detailed guidelines for verifying the geometric data or form. Parapet walls are considered shading surfaces	The geometry and orientation of the building were successfully created with a decrease in calculating room area and volume as the calculation method is based on the internal distance between walls. Parapet walls are part of the

	Parapet walls are considered a local shading element		external walls but are extended to 1 m above the rooftop surface
Construction materials	The layers were according to the construction sector in Jordan	The layers were according to the construction sector in Jordan. Does not transfer zero-layer thickness, such as the membrane layer in the Revit program	The layers were according to the construction sector in Jordan. However, REVIT has a limited library of materials, so the layers differ from other programs. It has a limitation due to not accepting zero-layer thickness, as it accepts the minimum thickness of 0.0008 mm
HVAC system	Cooling system: Air-conditioning Heating: Central heating radiators	Cooling system: Air-conditioning Heating: Central heating radiators	Split systems with mechanical ventilation and cooling
Occupancy operating schedule	Heating hours through the year: 777.6 hours Cooling hours through the year: 600 hours	Heating hours through the year: 777.6 hours Cooling hours through the year: 600 hours	Heating hours through the year: 777.6 hours Cooling hours through the year: 600 hours
Climate data availability and location	Does not provide specific climate conditions for All Jordanian cities	Does not provide specific climate conditions for All Jordanian cities	Provide specific climate conditions for each one of the Jordanian cities
Simulation engine	Apache Sim	Energy Plus	DOE 2.2

2.6. Weather Data Inputs comparison

2.6.1. Integrated Environmental Solution - Virtual Solution program

This program uses the Aplocate tool to determine the location of the simulation and the weather station near the specified location. This tool consists of four tabs: location and site data, design weather data, simulation weather data, and simulation calendar; also, the weather data information is shown in Table 2.

TABLE 2. WEATHER DATA CHARACTERISTICS FOR EACH CITY IN THE IES-VE PROGRAM

Location	Site data	Simulation weather file
Amman	Queen Alia International Airport	Jerusalem_IWEC.fwt
Mafraq	Mafraq King Hussein, Jordan	ISR_Jerusalem-Atarot.AP.401840_MSI.epw
Aqaba	Aqaba King Hussein Intl Airport, Jordan	ISR_Eilat.401990_MSI.epw

2.6.2. Design-Builder program

This program uses the Load location tool to determine the simulation location and the weather station near the specified location. This tool consists of two tabs: Target and Load data. Also, the weather data information is shown in Table 3.

TABLE 3. WEATHER DATA CHARACTERISTICS FOR EACH CITY IN THE DESIGN-BUILDER PROGRAM

Location	Site data	Simulation weather file
Amman	Queen Alia International Airport	ISR_JERUSALEM_IWEC
Mafraq	Mafraq	ISR_Jerusalem-Atarot.AP.401840_MSI.epw
Aqaba	AQABA AIRPORT	ISR_EILAT_MSI

2.6.3. Revit program

This program uses the Energy optimization tool from the Analyze tab to determine the location of the simulation and the weather station near the specified location. Also, the weather data information is shown in Table 4.

TABLE 4. WEATHER DATA CHARACTERISTICS FOR EACH CITY IN THE REVIT PROGRAM

Location	Site Data	Simulation weather file
Amman	Queen Alia International Airport	The weather station (1257549-2006)
Mafraq	Mafraq	The weather station (1258165-2006)
Aqaba	Aqaba International Airport, Jordan	The weather station (1255091-2006)

3. RESULTS AND DISCUSSION

The input data of the analyzed model were taken from local reliable Jordanian building codes for the current construction situation. Moreover, the output results were approximately like familiar research conducted in similar climate zones. The simulation process was also tested in three computational programs, which were previously stated in detail, to compare and validate results between them. Simulation programs indicate that the results of each program compared to another have a little difference, not more than 20 % variation. The final output of heating and cooling loads of each city in the three software was dropped in Table 5 and Table 6. On the other hand, Revit software differs from the other two software related to the characteristics of Revit; it calculates the area and volume of the space from the center of the interior walls, which results in evaluating different areas and volumes. Revit software does not allow more than one HVAC system, which tightened the circle to use only Air-conditioning. Also, Revit software does not have separate schedules for heating and cooling; it only has a power schedule for both heating and cooling, and Revit software has its weather data for all locations in Jordan; unlike other software that was used in this research, they have a nearby weather station for the Jordanian cities. Finally, the heating loads in the hot months have small values in Revit as it calculates the loads even if they are small, unlike other software that assumes those values are zero, and the same situation goes for the cooling loads.

TABLE 5. RESULTS OF THE THREE CITIES IN THREE SIMULATION PROGRAMS BEFORE INSTALLING THE PV SYSTEM

Before installation of the PV system			
City	Simulation software	Cooling Loads, MWh/year	Heating Loads, MWh/year
Amman	IES-VE	1.27	4.34

	DESIGNBUILDER	1.46	3.66
	REVIT	2.14	3.67
Mafraq	IES-VE	1.29	4.53
	DESIGNBUILDER	1.42	3.54
	REVIT	2.18	3.65
Aqaba	IES-VE	7.11	0.26
	DESIGNBUILDER	5.80	0.25
	REVIT	7.24	0.44

TABLE 6. RESULTS OF THE THREE CITIES IN THREE SIMULATION PROGRAMS AFTER INSTALLING THE PV SYSTEM WITH THE APPROPRIATE TILT ANGLE

After installation of the PV system				**Tilt Angle**
City	Simulation software	Cooling Loads (MWh/year)	Heating Loads (MWh/year)	
Amman	IES-VE	1.15	4.55	30°
	DESIGNBUILDER	1.45	3.68	30°
	REVIT	2.13	3.73	30°
Mafraq	IES-VE	1.13	4.72	32°
	DESIGNBUILDER	1.35	3.93	32°
	REVIT	2.17	3.94	32°
Aqaba	IES-VE	6.90	0.30	28°
	DESIGNBUILDER	5.51	0.22	28°
	REVIT	7.23	0.44	28°

4. CONCLUSION

This investigation is to provide a comparison between the most popular building performance simulation tools by developing a simulation process for a baseline model and its enhanced version in three climate zones (Humid Subtropical, Semi-Arid, moderate dry–warm) presented by three cities (Amman, Mafraq, Aqaba) characteristic summer and winter periods. The simulation tests the shading effect of solar panels on uninsulated rooftops in typical housing units. So, a transient-state 3D distributed thermal model of the PV-added rooftop components was developed using different ways of modeling in each software. The outcomes showed that the simulation process using the IES-VE simulation program resulted in a reduction in cooling loads in Amman city with a value of 9.45 %, while in winter, the results showed an increase in the heating loads with a value of 4.84 %, also a reduction in

Mafraq city with a value of 12.4 %. In comparison, in winter, heating loads increased by 4.2 %.

Moreover, the findings showed that Aqaba City witnessed a reduction of 2.95 % in cooling loads and an increase of 15.4 % in heating loads.

Using the Design-Builder simulation program showed a reduction in cooling loads in Amman city with a value of 0.69 %, while in winter, the results showed an increase in the heating loads with a value of 0.55 %, also a reduction in Mafraq city with a value of 4.9 %. In winter, heating loads increased with a value of 11 %. Moreover, the findings showed that Aqaba City went through a minimization in cooling loads with a value of 5 % and a decrease of 12 % in heating loads.

Furthermore, the last simulation program (Revit) presented a reduction in cooling loads with a value of 0.46 % and a rise in heating loads with 1.6 % in Amman city. In comparison, Mafraq city marked a decrease in cooling loads as well, with a rate of 0.46 %, and an increase in heating loads in winter, with a total of 7.95 %. Finally, Aqaba City endorsed a reduction in cooling loads with a value of 0.14 % and no change in the heating load results.

To finalize, the results of the IES-VE program indicate that Mafraq city benefits the most from the shading effect of installing PV panels as the gain in energy is 8.15 %, which is 0.082 MWh/year. Furthermore, according to the results, the Design-Builder showed that Aqaba City profits from the shading effect of the PV system the most, as the gain in the total energy contribution is 16.8 %, equal to 0.168 MWh/year. The results underscore and validate the purpose of this work and can be used as the basis for suggestions to energy officials, the construction industry, and consumers. A rooftop solar panel also gives a deeper understanding of facilities' HVAC energy demand fluctuation, which is essential in the current construction situation.

Finally, it is recommended to use another simulation program on the same case study to deal with different interfaces. Also, it would be beneficial to conduct an analysis of other climate zones in the world. This research focuses on using three simulation software and comparing their specifications and findings with significant discrepancies between them; however, we can advise using the Integrated Environmental Solution-Virtual Solution software for its high accuracy and ease of use.

REFERENCES

[1] The Ministry of Energy & Mineral Resources Annual Report, 2017. [Online]. [Accessed: 11.10.2022]. Available: https://www.memr.gov.jo/ebv4.0/root_storage/en/eb_list_page/annual_report_2017.pdf

[2] Jordan News. Jordan's fuel imports rose by 61% through October 2022. [Online]. [Accessed: 11.11.2022]. Available: https://www.jordannews.jo/Section-113/All/Jordan-s-fuel-imports-rose-by-61-through-October-2022-26147

[3] Jaber J. O., Probert S. D. Purchased-energy consumptions in Jordan's commercial and public-service sector. [Online]. [Accessed: 10.12.2022]. Available: www.elsevier.com/locate/apenergy

[4] Kapsalis V. C., Vardoulakis E., Karamanis D. Simulation of the cooling effect of the roof-added photovoltaic panels. *Advances in Building Energy Research* 2014:8(1):41–54. https://doi.org/10.1080/17512549.2014.890534

[5] Rizeq N. S. Hammad. Photovoltaic System to Save Energy in Jordan: A Case Study on a Semi-detached House. *Journal of Energy and Power Engineering* 2019:13(1). https://doi.org/10.17265/1934-8975/2019.01.004

[6] Friedrich-Ebert-Stiftung. Amman Office. A guide to renewable energy in Egypt and Jordan: current situation and future potentials.

[7] Jaber J. O., *et al.* Renewable energy education in faculties of engineering in Jordan: Relationship between demographics and level of knowledge of senior students. *Renewable and Sustainable Energy Reviews* 2017:73:452–459. Elsevier Ltd. https://doi.org/10.1016/j.rser.2017.01.141

[8] Brix M. General rights Rural electrification through private models: the case of solar-powered mini-grid development in Kenya: Exploring the hybrid nature of private business models and the interplay between new players and existing structures in the Kenyan rural electrification regime. 2022.

[9] Song Y. ling, Darani K. S., Khdair A. I., Abu-Rumman G., Kalbasi R. A review on conventional passive cooling methods applicable to arid and warm climates considering economic cost and efficiency analysis in resource-based cities. *Energy Reports* 2021:7:2784–2820. https://doi.org/10.1016/j.egyr.2021.04.056

[10] Mazzeo D., Kontoleon K. J. The role of inclination and orientation of different building roof typologies on indoor and outdoor environment thermal comfort in Italy and Greece. *Sustainable Cities and Society* 2020:60:102111. https://doi.org/10.1016/j.scs.2020.102111

[11] Ozarisoy B., Altan H. Systematic literature review of bioclimatic design elements: Theories, methodologies and cases in the South-eastern Mediterranean climate. *Energy and Buildings* 2021:250:111281. https://doi.org/10.1016/j.enbuild.2021.111281

[12] Alyami M., Omer S. Building energy performance simulation: a case study of modelling an existing residential building in Saudi Arabia. *Environmental Research: Infrastructure and Sustainability* 2021:1(3):035001. https://doi.org/10.1088/2634-4505/ac241e

[13] Emil F., Diab A. Energy rationalization for an educational building in Egypt: Towards a zero energy building. *Journal of Building Engineering* 2021:44:103247. https://doi.org/10.1016/j.jobe.2021.103247

[14] Khdair G. Abu Rumman, Basha M. Developing building enhanced with PCM to reduce energy consumption. *Journal of Building Engineering* 2022:48:103923. https://doi.org/10.1016/j.jobe.2021.103923

[15] Pisello L., Pignatta G., Castaldo V. L., Cotana F. Experimental analysis of natural gravel covering as cool roofing and cool pavement. *Sustainability (Switzerland)* 2014:6(8):4706–4722. https://doi.org/10.3390/su6084706

[16] Tong S., *et al.* Thermal performance of concrete-based roofs in tropical climate. *Energy and Buildings* 2014:76:392–401. https://doi.org/10.1016/j.enbuild.2014.02.076

[17] Food and Agriculture Organization of the United Nations. Environmental and social management framework building resilience to cope with climate change in Jordan through improving water use efficiency in the agriculture sector (BRCCJ). 2020.

[18] Ababsa M. In Atlas of Jordan: History, Territories and Society. Beyrouth: Presses de l'Ifpo, Institut français du Proche-Orient, 2013. https://doi.org/10.4000/books.ifpo.4560 (In French).

[19] The National Climate Change Adaptation Plan of Jordan 2021. [Online]. [Accessed: 12.10.2022]. Available: http://www.moenv.gov.jo/ebv4.0/root_storage/ar/eb_list_page/final_draft_nap-2021.pdf

[20] Worldwide weather forecasts and climate information. [Online]. [Accessed: 16.10.2022]. Available: https://weather-and-climate.com/

[21] Nematchoua M. K., *et al*. Application of phase change materials, thermal insulation, and external shading for thermal comfort improvement and cooling energy demand reduction in an office building under different coastal tropical climates. *Solar Energy* 2020:207:458–470. https://doi.org/10.1016/j.solener.2020.06.110

[22] Ogbeba J. E., Hoskara E. The evaluation of single-family detached housing units in terms of integrated photovoltaic shading devices: The case of Northern Cyprus. *Sustainability (Switzerland)* 2019:11(3):593. https://doi.org/10.3390/su11030593

[23] Ascione F., Bianco N., Iovane T., Mastellone M., Mauro G. M. Is it fundamental to model the inter-building effect for reliable building energy simulations? Interaction with shading systems. *Building and Environment* 2020:183. https://doi.org/10.1016/j.buildenv.2020.107161

[24] Samuelson H. W., Reinhart C. F. Modelling an existing building in DESIGNBUILDER/ENERGYPLUS: CUSTOM VERSUS DEFAULT INPUTS. 2009. [Online]. [Accessed: 19.09.2022]. Available: https://www.researchgate.net/publication/228453444

[25] Soundarya R., Uma R. N. Building information modelling of a two storey building using AUTODESK REVIT and AUTODESK NAVISWORK MANAGE. [Online]. [Accessed: 17.09.2022]. Available: www.iaset.us

[26] Framework for the transfer of building materials data between the BIM and Thermal simulation software.

[27] Al-Doury R. R. J., Ibrahim T. K., Salem T. Opportunity of Improving the Thermal Performance of a High-performance University Building Based on Revit Software Development of novel surfaces for heat transfer augmentation View project Coal-Fired Power Plants View project. 2020. [Online]. [Accessed: 11.10.2022]. Available: https://www.researchgate.net/publication/344372806

[28] UK ENERGY IN BRIEF 2020. 2020. [Online]. [Accessed: 13.10.2022]. Available: www.gov.uk/government/statistics/uk-energy-in-brief-2020

[29] Al-Saeed Y. W., Ahmed A. Evaluating design strategies for nearly zero energy buildings in the middle east and North Africa regions. Designs (Basel). 2018:2(4):35. https://doi.org/10.3390/designs2040035

[30] Monna S., Abdallah R., Juaidi A., Albatayneh A., Zapata-Sierra A. J., Manzano-Agugliaro F. Potential electricity production by installing photovoltaic systems on the rooftops of residential buildings in Jordan: An approach to climate change mitigation. *Energies* 2022:15(2):496. https://doi.org/10.3390/en15020496

[31] Albatayneh R., Albadaineh A., Juaidi A., Abdallah R., Zabalo A., Manzano-Agugliaro F. Enhancing the Energy Efficiency of Buildings by Shading with PV Panels in Semi-Arid Climate Zone. *Sustainability* 2022:14(24):17040. https://doi.org/10.3390/su142417040

[32] Albatayneh A., Albadaineh R., Juaidi A., Abdallah R., Montoya M. D. G., Manzano-Agugliaro F. Rooftop photovoltaic system as a shading device for uninsulated buildings. *Energy Reports* 2022:8:4223–4232. https://doi.org/10.1016/j.egyr.2022.03.082

[33] Altun AF, Kiliç M. Influence of window parameters on the thermal performance of office rooms in different climate zones of Turkey. *International Journal of Renewable Energy Research* 2019 Mar 21:9(1):226–243.
[34] Johansson D., Bagge H., Wahlström Å. Springer Proceedings in Energy Cold Climate HVAC 2018 Sustainable Buildings in Cold Climates. [Online]. [Accessed: 24.11.2022]. Available: http://www.springer.com/series/13370
[35] Albatayneh A., Alterman D., Page A., Moghtaderi B. Temperature versus energy based approaches in the thermal assessment of buildings. *Energy Procedia* 2017:(128):46-50. https://doi.org/10.1016/j.egypro.2017.09.013
[36] Albatayneh A., Alterman D., Page A., Moghtaderi B. Discrepancies in peak temperature times using prolonged CFD simulations of housing thermal performance. *Energy Procedia* 2017:115:253–264. https://doi.org/10.1016/j.egypro.2017.05.023
[37] Albatayneh A., Alterman D., Page A. W., Moghtaderi B. Warming issues associated with the long term simulation of housing using CFD analysis. *Journal of Green Building* 2016:11(2):57–74. https://doi.org/10.3992/jgb.11.2.57.1
[38] Albatayneh A., Alterman D., Page A., Moghtaderi B. The significance of sky temperature in the assessment of the thermal performance of buildings. *Applied Sciences* 2020:10(22):8057. https://doi.org/10.3390/app10228057
[39] Albatayneh A., Jaradat M., AlKhatib M. B., Abdallah R., Juaidi A., Manzano-Agugliaro F. The significance of the adaptive thermal comfort practice over the structure retrofits to sustain indoor thermal comfort. *Energies* 2021:14(10):2946. https://doi.org/10.3390/en14102946
[40] Muhaidat J., Albatayneh A., Assaf M. N., Juaidi A., Abdallah R., Manzano-Agugliaro F. The Significance of Occupants' Interaction with Their Environment on Reducing Cooling Loads and Dermatological Distresses in East Mediterranean Climates. *International Journal of Environmental Research and Public Health* 2021:18(16):8870. https://doi.org/10.3390/ijerph18168870
[41] Albatayneh A., Assaf M. N., Jaradat M., Alterman D. The Effectiveness of Infiltration against Roof Insulation aimed at Low Income Housing Retrofits for Different Climate Zones in Jordan. *Environmental and Climate Technologies* 2020:24(3):11–24. https://doi.org/10.2478/rtuect-2020-0082
[42] Albatayneh A., Alterman D., Page A., Moghtaderi B. An alternative approach to the simulation of wind effects on the thermal performance of buildings. *International Journal of Computational Physics Series* 2018:27(1):35-44. https://doi.org/10.29167/A1I1P35-44
[43] Albatayneh A., Juaidi A., Abdallah R., Pena-Fernandez A., Manzano-Agugliaro F. Effect of the subsidised electrical energy tariff on the residential energy consumption in Jordan. *Energy Reports* 2022:8:893–903. https://doi.org/10.1016/j.egyr.2021.12.019
[44] Juaidi A., Muhammad H. H., Abdallah R., Abdalhaq R., Albatayneh A., Kawa F. Experimental validation of dust impact on-grid connected PV system performance in Palestine: An energy nexus perspective. *Energy Nexus* 2022:6:100082. https://doi.org/10.1016/j.nexus.2022.100082
[45] Abdallah R., Juaidi A., Savaş M. A., Çamur H., Albatayneh A., Abdala S., Manzano-Agugliaro F. A critical review on recycling composite waste using pyrolysis for sustainable development. *Energies* 2021:14(18):5748. https://doi.org/10.3390/en14185748
[46] Sameer Baamer A., Bruton K., O'sullivan D. A Comparative Analysis of Energy Simulation Tools for Architectural Research: A Case Study of a Typical House in Saudi Arabia. Proceedings of BSO-V. 21–22 September 2020, Loughborough, UK.
[47] Muslim S. A. EnergyPlus-Towards the Selection of Right Simulation Tool for Building Energy and Power Systems Research. *Journal of Energy and Power Technology* 2021:3(3):034. https://doi.org/10.21926/jept.2103034