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Review Paper

Review on Energy Efficiency using the Ecotect Simulation Software for Residential Building Sector

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A B S T R A C T

The building sectors are recognized as one of the essential contributors of global warming and climate change because of their high energy use. The building sector is responsible for 40% of all energy usage and 40% of the CO_2 emissions in the developed countries. Researchers in the world are working on energy management and conservation using simulation software to develop strategies that lead to an overall reduction of energy consumption in the buildings. This review is considered a modeling and simulation approach with a specific focus on residential building. Modeling and simulation methods reviewed are presented categorically as per the strategic approach adopted by the researchers. Simulation results available for residential building energy are also introduced. This research has reviewed the capabilities and performances on Ecotect simulation and modeling, including daylighting, solar radiation, thermal analysis, and shading for energy management and conservation of residential building. Different modeling and simulation approaches, from various building and climate, were reviewed and discussed. The analysis of present work greatly help the researchers' decision-making and selection of software to perform various simulations in energy management of residential buildings.

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INTRODUCTION

Papers Nowadays, the worldwide environmental change has made a risk to the human civilization. An effective indoor condition relies upon a comprehension of the ecological components, including building structure and setting. Indoor climatic conditions played critical role in sustainability in building construction [1–3]. The microclimate encompassing the structure is emphasized through the interaction of different structures or the regular habitat, which a significant factor in the event of building energy demand and indoor building environment [4]. Thermal comfort in human body is related with a few elements like: air temperature, air development, measure of apparel worn, and action level including an individual's body itself [5]. Over the most recent couple of decades, the pace of residential building investments has become quickly because of the all-inclusive community development and the grouping of most of the populace [6, 7]. The vast majority of these buildings were constructed without focusing on environmental impact on these structures, which prompted active air-conditioning to bear the cost of warm indoor temperature and sufficiently bright indoor spaces [8]. Numerous underdeveloped nations adhere to the structure rules and development standards without pondering climate contrasts [9]. The worries over a dangerous atmospheric condition and requirement for decrease of high emission of greenhouse gases encourage the usage of methodologies for indoor climate conditions in advancing agreeable indoor condition [10].

A sustainable building is developed utilizing materials that could hardly harm the environment, by means of low energy consumption for the whole lifecycle of the

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building [11–18]. As of now, worry about environmental change and asset exhaustion issues is expanding the world over [10]. Vitality utilization and ozone harming substance discharges to the earth ascribed to buildings are huge supporters of this environmental impact [10]. Buildings and its energy impact environment greatly, presently a matter of concern among the research fraternity [19]. With the growing population and expectations for everyday comforts, energy issues are turning out to be very significant today on account of a potential deficiency of energy in near future [20]. Around the world, the different institutes assessed that 40% of the world's energy and 16% of the water utilized by the buildings every year [21]. Building Design Strategies are applied three principal areas: environment, climate and energy; as they are required for energy conservation [22, 23]. As worldwide interests move in the direction of energy efficiency in buildings in the current situation of environmental change, thermal comfort studies are increasing tremendous significance [24–28]. In any case, it is to refer here that 95% of them are high energy consumption buildings and energy consumption of buildings has just represented 46.7% of the all-out social energy utilization [29]. In this way, pushing ecological energy-saving and constructing green buildings in many countries became exceptionally fascinating [30–34]. The voice about low-carbon economy and energy conservation and emission reduction around the globe is stronger particularly since the United Nations Climate Change Conference in 2009 [35–38]. This development in building energy consumption can affect the world badly, in light of the fact that the petroleum derivatives are the essential hotspot for most of the energy [39].

The reminder of the study is organized as follows. First, this research introduces the energy efficiency in residential buildings; second, explains the building energy simulation in Ecotect software; and finally, reviews and discusses detailed literature review of the research studied and also presents a brief to the performance of Ecotect simulation software in different residential buildings with different climates. Each of these analyzes has different outputs based on the goals of the researchers. A comprehensive review of software performance involved in Ecotect modeling and simulation is also presented. A table wise brief of all the energy analysis of residential building using Ecotect program presented in the result section.

ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS

All Inhabitants' conduct and exercises moderately add with the impact of worldwide temperature change, subsequently, of building energy consumption and carbon outflow [40, 41]. Climatic effect in developing countries buildings are because of high intensity of solar radiation and high daily air temperature [19, 42, 43]. Driven by the interest for expanding energy efficiency advancements, technologies, architects and engineers attempt to provide ecological and energy saving strategies in the earlier design process, by using simulating software to analyze the building physical environment and predict the energy consumption; thus, integrating the architecture into a scientific and organic component [44–50].

In the most regions, the residential energy consumption has dispensed an enormous level of national concern [51]. In building industry, the architecture-based climatic conditions and regard for vitality sparing is an extraordinary rule for having the best productivity in residential sector [52, 53]. The building and construction sectors are recognized as one of the essential contributors of global warming and climate change because of their high energy usage [54, 55]. The building sector is responsible for 40% of all energy usage and 38% of the CO_2 emissions in the United States [56]. About 27% of the CO_2 emissions in UK are attributed to the building (Heat loss in your home). Thermal aspect of the building operational energy is one of the key points to be investigated since it has the main proportion of operational energy consumption of the buildings [12, 57]. The building sector (commercial, residential, and industrial) is responsible for 30–50% of the total energy demand of a society [58]. The average energy consumption of the building sector is responsible 50% energy consumption according to the Economic and Social Commission for Western Asia [59].

BUILDING ENERGY SIMULATION IN ECOTECT

Building energy simulation is achieving wide use as a cost-effective method of supporting energy efficient plan and the following operation and maintenance of buildings [60–62]. These simulations are such as the evaluation of the performance of energy-conservation technique and architectural concepts [63–67]. Among the few tools, Ecotect is the only software that has a capability to have a simple thermal performance analysis, fairly accurate and especially visually responsive [68–71]. For verifying the output, Ecotect utilizes a wide scope of graphical methods which can be saved as Metafiles, Bitmaps or animations. Similarly, many researchers' studies have used by this software in order to evaluate the required design configurations in their studie [72–75]. In 2005, the US Department of Energy analyzed 20 energy programs to give a review of their highlights and abilities. Energy software is characterized complete building simulation and analysis program [76]. One of the most remarkable highlights that Ecotect proposals is its capacity to see examination brings about different organizations, for example, graphs, tables, and 3D objects [77]. Ecotect is an ecological examination apparatus which can reproduce building execution directly in the chamber choice stage [78].

Ecotect energy simulation software allows geometrical modeling, implementation of thermal and lighting analysis to the same model in the same program while profiting by an intuitive and easy to use user-friendly [79, 80]. Among many computer-based applications, Ecotect program is the efficient technique due to its facilities with respect to making a perfect induction about thermal performance of the building and well-appearance user interface, which is easily used by architects [80, 81]. Ecotect is a comprehensive building and environment simulation tool that is used for the energy efficiency of climatic conditions such as solar radiation, daylighting, and thermal comfort [82]. In many research, Autodesk Ecotect and Meteonorm are used on the thermal analysis in typically-design residential building [83]. Ecotect is program that can perform thermal, lighting and acoustic analyses of building [1]. With the perception of passive design, Ecotect analysis was performed to simulate and investigate the building performance to contemplate the after effects of minimum energy consumption and sustainable power source use through coordinating and advancing the frameworks of energy conservation technology provided for the building [84]. Ecotect analysis helps to achieve visual architectural design and analysis tool that links a 3D designer with an extensive range of execution analysis functions covering thermal comfort, energy efficiency, lighting, shading, solar radiation [85, 86]. Autodesk Ecotect analysis is building analysis software that helps to achieve various tools building design and investigation. It is equipped towards environmentally conscious and green building design, making use of 3D models to visualize output [52, 87]. Ecotect analysis offers a wide scope of simulation and building energy analysis which can improve performance of existing buildings as well as new buildings plans [57, 85–90]. Online energy, water, and carbon discharge analysis capabilities incorporate with tools that empower architects to review and reproduce a building's performance within the context of its environment [91, 92]. Ecotect implements building design and energy analysis tool that includes a broad range of simulation and analysis practice required to study how a building design will operate and perform [93, 94]. Ecotect covers efficiency analysis which is simple, accurate, and visually responsive [90]. Ecotect is one of only a handful hardly any tool in which thermal performance analysis can be done easily, genuinely precise and, above all, outwardly responsive.

Looking at the previous research, it can be concluded that there is no comprehensive review on the use of Ecotect simulation software to study the building energy analysis and their effects on energy efficiency of residential building sector in different climate zone.

REVIEW AND DISCUSSION

Previous research has discussed on application of Ecotect simulation software on energy efficiency in residential building. Moreover, in this section the reviews of Ecotect are summarized in residential building for a simulation and modeling method.

The building performance in energy and lighting is evaluated in Madenaty city of Egypt by Aldali and Moustafa [6]. The assessment was performed using computer-aid simulation software called Ecotect [6]. A case study was chosen as high-income houses located in Madenaty city in New Cairo, Egypt [95]. Ecotect was introduced as the simulation software that permit to have geometrical modeling, lighting and thermal performance analysis in the same model and program with user friendly and collective interface. Result displays the distribution of daylight on a (+0.6, +3.9 m) level. It shows the average daylight factor increases 1.17% in compare with previous design and become 5.92%. The minimum required daylight for living space and corridor are 300 and 50 lux, respectively. The minimum daylights for living space and corridor are 321 lux and 82 lux, respectively. That, indicate no requirement using the additional artificial lighting system in the morning and saving energy [96]. According to findings the heating loads are lower since the modification is applied in opening ratio. The author has discussed about the efficiency of modeling realities in window wall ratio (WWR) which leads to have 6 different models with up/down variation (67:142%) by applying daylight factor rather than the baseline model. The results indicated the up/down variation (88:109%) in heating and cooling loads rather than baseline model. 1.5 kW at 05:00 on 23rd February is maximum heating and 17 kW at 14:00 on 27th May is maximum cooling [96].

The degree of the thermal environment was studied in building (residential) located in Malaysia by Jamaludin et al. [1]. It was applied at three different microclimate zones include of Kuala Lumpur (KL), Kuching (K), and Bayan Lepas (BL) [1]. The Autodesk Ecotect and Meteonorm were considered to apply in this research to perform thermal analysis in residential building with normal design located in Malaysia. A two story building (residential) with 159.80 m^2 floor area and 3.0 m height is developed. As it was mentioned in the result, the Master Bedroom attained the highest indoor temperature in Kuala Lumpur weather condition at 1400 hours. The indoor temperatures located in Kuching carries the lower value in the most rather than Kuala Lumpur and Bayan Lepas. All over, the simulated indoor temperatures are more than the proposed indoor design by MS 1525:2007 in thermal relief (Figure 1) [1].

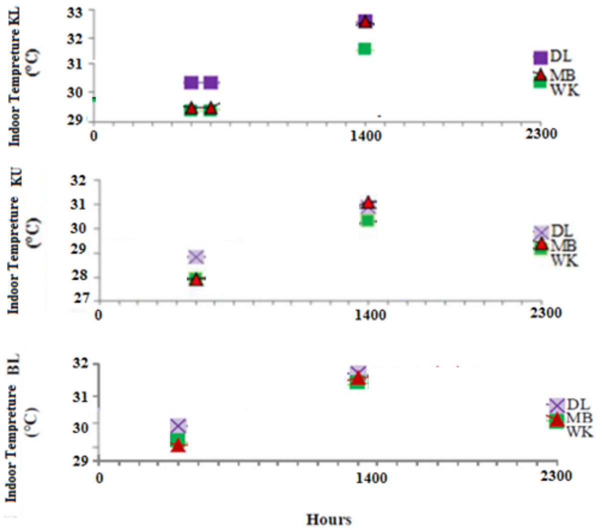

Figure 1. Indoor temperature in KL, KU, and BL climate

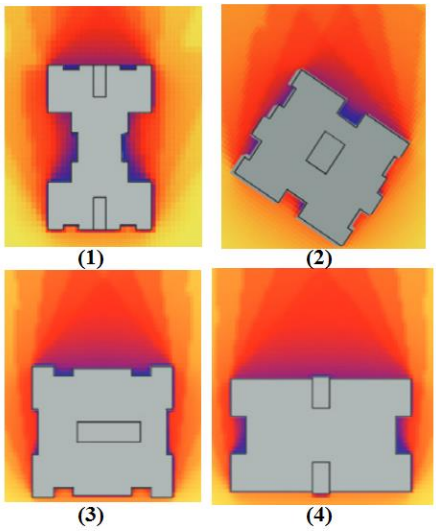

Figure 3. Solar simulation of four types in residential buildings

A small size empirical building was integrated with the objective-based idea called passive house in Hangzhou weather condition by Wu and Gao [84]. The energy consumption and indoor hourly temperature are two main keys to evaluate building envelope including insulated and non-insulated by the use of Ecotect Analysis software [43]. The research shows the most appropriate slanted roof needs to have 22° to reach to maximum solar energy absorption in Hangzhou which was extracted from solar radiation simulation. It results in having solar energy with full usage capacity. The result shows that the average value of solar radiation access on sloping roof is 1,211 kWh. This amount is 11% higher than the horizontal roof of 1,089 kWh (Figure 2) [84].

The typical simulation models of Maskan Mehr complex residential buildings located in Iran performed by Faizi et al. (Figure 3) [52]. This study applied Ecotect software to extract the amount of the energy consumption using different approaches including shadows, overshadowing, lighting simulation, solar radiation, and thermal performance among four different types of buildings. The simulation results are summarized in Table 1 [52].

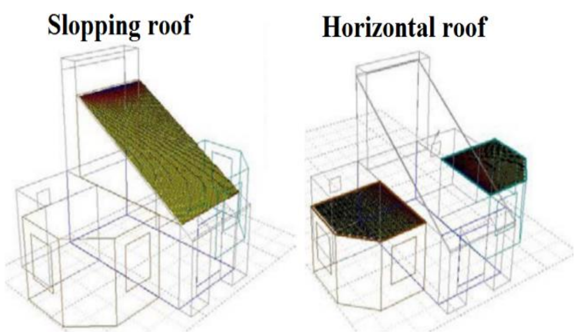

Figure 2. Solar radiation accessibility on the slopping

Autodesk Ecotect Analysis software was applied by Wu and Jo [78]. Initially the field geometrical parameters have been used to confirm the 3D model, the required functions provided in the tool bar of Ecotect apply to analyze the location information. Table 2 shows the building information in this study area.

The most reliable building orientation is shown in Figure 4 by deploying Autodesk Ecotect Analysis tool. The best and worst building orientation was indicated

Table 1. The features of optimal pattern

	Building 1	Building 2	Building 3	Building 4
Shading	■	×	×	×
Solar Radiation	×	■	×	×
Daylighting	×	■	×	×
Thermal Analysis	■	×	×	×

Table 2. Building information

Building floor	Number of Buildings	Height (m)
19	1	57
18	4	54
16	2	48
15	7	45
14	3	42
13	3	39
12	1	36
1	4	4

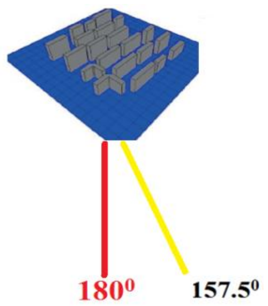

Figure 4. Simulation and analysis of the best building orientation

with 157.5° (south by east 22.5°) and north by east 67.5°, respectively [78]. It leads to resist against under heated and overheated condition.

The thermal relief is performed in residential building using Ecotect tool by Sadafi et al. [42]. A case study was defined a two-story building with 219 m^2 area and terrace house type located in Malaysia. In computational empirical, baseline model development is the initial step by use of field measurement analysis. Then, Ecotect software is applied to evaluate the thermal condition of the building (terrace house). The source of building material is extracted from either user defined library or Ecotect library. In addition, Energy Plus webpage is the main reference to export the weather data file. The field measurement outputs demonstrated the building (terrace house) keep thermal comfort in around 15 h, that usually occur in the night [42].

The potential replacement material structures were evaluated by Shoubi et al. [12] to extract the most suitable energy performance. It was performed by Autodesk Ecotect analysis and Revit Architecture 2012 software to display the potential materials that can reach to the maximum amount of operational energy reduction along its yearly life cycle [12]. The degree of surface solar energy absorption in the specified direction and position of the building is calculated with Ecotect software. The best and worst building orientations is 37.5° and 127.5° from the north respectively [12]. As the results showed the presence of alternative materials including reverse brick veneer and doble-brick (replaced in the wall components), timber (replaced in windows components), concrete floor-tiles (replaced in floors components), plaster insulation (replaced in ceilings components), glass (replaced in doors components) lead to be more energy efficient in comparison with other defined materials. It is clear that modify the baseline design with carful and alternative design result in reducing to 12,580 kWh in building energy yearly amount.

To propose a better utilization of light-wells in residential building, Ahadi et al. [100] determined the effect of some affecting variables on the daylighting performance of light-wells. Daysim software has been used to run 352 computer simulations to evaluate the mentioned variables. In addition, the graphical use interfaces of Daysim has been provided by Autodesk Ecotect software. The residential building located in Tehran is the case study in this research. In light-wells, the outputs indicate presence of angle wall has better daylight performance [97].

In Penang, Malaysia, Ecotect software was applied to the residential building to evaluate the envelope design on energy cooling load [19]. The high-rise building cooling system requirement can be reduced using the passive-based design method based on developed building design envelope as authors were recommended. The outputs show the best technique in both maximum cooling load and cooling energy load reduction is providing the thermal insulation in exterior wall. It leads to reach 26.3% and 10.2% reduction in maximum cooling load and cooling energy load respectively.

Depend on the configurations of the window, the Predicted Mean Vote (PMV) index was developed for 14 different feasible layouts in room for thermal comfort simulation by Anand et al. [98] (Figure 5). Three selected climatic areas located in India simulated the performance based on measured in-situ from one the proposed area.

The validation of outputs was done by measured in-situ extracted from Channai. The results were extended in order to find the PMV in normal ventilated residential areas located in New Dehli and Bangalore [98].

The energy saving approaches and meteorological data was analyzed by Yang et al. [99]. They are correlated with local environment by use of Ecotect tool for planning of residential. Some of the parameters like building orientation, natural ventilation condition, and building daylight have been evaluated. The best condition of building orientation was 172.50 [99].

The atria energy consumption was analyzed by Amani in different hot and dry climate zones. Ecotect software was applied to simulate and define the starting point with local climate conditions. Therefore, the selection of most appropriate atrium for residential buildings energy efficiency proceeded to perform the energy consumption [100]. The energy distribution and hourly solar exposure fabric gain of building were the parameters which were preceded for analysis. The purpose of this study is to apply optimum atrium in hot and dry weather condition

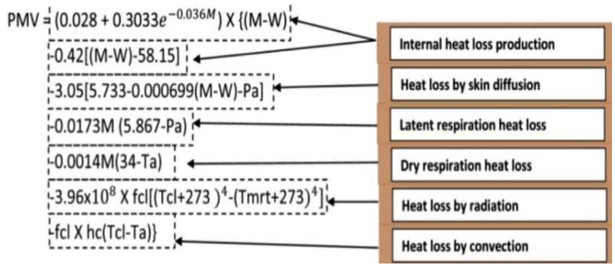

Figure 5. Inputs and equations to compute PMV

in building related to warm seasons energy saving. Based on Ecotect analysis procedure, less solar absorption leads to reduce the energy consumption which result in having four-side atrium with radiation absorption 902,795 W, radiation incident 2,506,027 W, and radiation transmission 297,118 W is the best choice in hot summer [100].

One story building including two weather conditions was evaluated and simulated by Amani [101]. In order to find the most appropriate atrium in cold, dry and hot weather condition zones in the building, two case were analyzed completely. Ecotect energy tool was considered to simulate all schemes in this study. The setting of Ecotect compose of wide current speed, people cloth in work continuous situation, humidity quantity, passageway space light quantity, average number of present people in the light thermal zone, internal attraction quantity, work plan, and relief domain of the building zones. Apparently, the consumption of gas energy is high during the winter season. Therefore, the solar energy absorption needs to be shown the most and relatively least transmission. Moreover, the consumption of electrical energy is very high in summer. Then, the solar energy absorption and solar energy transmission are least and most respectively. Based on Ecotect 5.6 analysis, when solar absorption is low, energy consumption become lower, and leas to have four-side atrium with radiation absorption of 902,795 and 29,057 W, radiation transmission of 297,118 and 4,201 W and radiation incident of 2,506,027 and 69,613 W in hot summer and in cold winter become the optimized choices [101].

The simulated building model was analyzed using conventional villas comparison by Krishnaraj et al. [102]. The eQUEST software preceded the simulation analysis in daylight analysis section of Ecotect software. The two ground and first floors are analyzed in daylighting. The daylight simulation outputs are related to sky with clear condition at noon on 21st September for both ground and first floors. The simulations show around 50% of residential filled areas in every peopled unit export at least 10-foot candles (FC) daylight illuminance (108 lux) in a situation of having pellucid light on 21st September at 12 PM at a working flat.

A comparison study among the UDI percent, indoor temperature hours/years, and residential building orientation in global directions was introduced by Dabe and Adane [103]. The temperature distribution tool in Ecotect software has performed the analysis. The outputs displayed the right-hand side of balcony became 0.65 m after 1 m reduction (initially was 1.65 m) and make 64° horizontal shading angle with window, and left-hand side reached to 1.40 m after 1 m reduction (initially was 2.40 m) and make 37° horizontal shading angle with window.

RESULTS

Simulation of residential building energy using Ecotect software depends on its application, types of analysis it will be used, climate and location condition, and building information. The first step is building design such as assign materials to walls, ceilings, floors, and windows. After that the data information is entered. These data include weather data, the number of user, thermal comfort zones. Ecotect software performs the analysis and simulation and finally provides outputs based on the type of request. These outputs can be included daylighting, shading, thermal and solar radiation. Table 3 provides a detailed wise summery of modeling approach identified within review and discussion within section 4, that have been discussed.

Table 3. Summary of simulating approaches of residential building energy using Ecotect software

Ref.	Type of Building	Climate	Location	Simulation and Analysis				Results
				Daylighting	Shading	Thermal Analysis	Solar radiation	
[1]	Double-storey residential building	Hot and dry	Kuala Lumpur Malaysia			✓		Analysis of highest indoor temperature
[6]	Two duplex residential flats	Mild Mediterranean	New Cairo Egypt	✓		✓		Analysis of heating and cooling loads
[12]	A double story bungalow house	Warm with high humidity	Johor Malaysia			✓	✓	Reduce building energy consumption
[19]	Two towers (A and B) each 29-stories high	Warm with high humidity	Penang Malaysia		✓	✓		Energy efficiency using exterior wall thermal insulation
[23]	Iterative economic units	Mild Mediterranean	Marsa Matrouh Egypt	✓		✓		The pitched roofed building for good ventilation

[43]	A double storey terrace house	Warm with high humidity	Kuala Lumpur Malaysia		✓	✓		The temperature reduction after introducing the courtyard in the months of March, June and December.
[52]	Complex buildings	Hot summer and cold winter	Iran	✓	✓	✓	✓	-
[78]	25 buildings consisting of four apartments/ five measurement sites	Hot summer	Chuncheon Korea		✓			Identification of the best building orientation
[84]	A small single-story	Hot summer and cold winter	Hangzhou China	✓		✓	✓	Identification of the best angle of sloping roof for obtaining the maximum quantity of the solar energy
[97]	Multi-storey, deep-plan and compact residential building	Semi-arid	Tehran Iran	✓				Cylindrical light-wells is better than the common form of light-wells
[98]	The 14 different room layouts	Humid; Moderate; Moderate and humid	Chennai; Bangalore; New Delhi; India			✓		For moderate climates, Find the best thermal comfort conditions for nights, and the day using the windows analysis
[99]	Residential state	Hot and humid summer, cold and wet winter	Ma'anshan China			✓	✓	Ecological energy-saving planning
[100]	Residential building 1 floor	Hot and dry	Kerman Iran			✓	✓	Identification of the optimum atrium for residential building in hot summer.
[101]	Residential building 1 floor	Hot and dry summer and cold and dry winter	Kerman Iran			✓	✓	Identification of the optimum atrium for residential building in hot summer and in cold winter
[102]	Villa; No of storeys, 3573 feet^2	Warm and humid	Thiruvanmiyur India	✓				The optimization of daylighted area in the sustainable building
[103]	Residential building	Hot and dry	Nagpur India	✓	✓	✓		Analysis of four building orientation by comparing useful UDI
[104]	Residential building	Mild	Rasht Iran		✓	✓	✓	Energy efficiency using comparison analysis of the main building components

CONCLUSION

The problems of building energy play an important role in the environment and the use of non-renewable energy. The residential building sectors are identified as one of the essential contributors of global warming and climate change because of their high energy usage. Ecotect software offers daylighting analysis, thermal performance analysis, shading program, and solar radiation. This software to simulate and investigate the building performance to contemplate the after effects of minimum energy consumption and sustainable power source use through coordinating and advancing the frameworks of energy-saving technology provided for the building. Ecotect analysis helps to achieve visual architectural design and analysis tool that links a comprehensive 3D modeler with a vast range of execution analysis functions covering thermal, energy, lighting, shading, acoustics, and solar aspects.

This research reviewed the capabilities and performances on Ecotect simulation and modeling, including daylighting, solar radiation, thermal analysis, and shading for energy management and conservation of residential building. Different modeling and simulation approaches, from various building and climate, were reviewed and discussed. The results presented in section 5 show that the Ecotect has high capability and performance in building energy modeling and analysis. The results of this study greatly help the researchers' decision-making and selection of software to perform various simulations in energy management of residential buildings.

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Persian Abstract

چکیده

بخش‌های ساختمانی به دلیل مصرف بالای انرژی به عنوان یکی از عوامل اصلی گرمایش جهانی و تغییرات آب و هوایی شناخته می‌شوند. بخش ساختمان ۴۰ درصد کل مصرف انرژی و ۴۰ درصد از انتشار CO_2 در کشورهای توسعه یافته است. محققان در جهان با استفاده از نرم‌افزارهای شبیه‌سازی بر روی مدیریت و حفظ انرژی کار می‌کنند تا استراتژی‌هایی را توسعه دهند که منجر به کاهش کلی مصرف انرژی در ساختمان‌ها شود. این بررسی یک رویکرد مدل‌سازی و شبیه‌سازی با تمرکز خاص بر ساختمان مسکونی در نظر گرفته شده است. روش‌های مدل‌سازی و شبیه‌سازی بررسی‌شده به‌طور قطعی بر اساس رویکرد استراتژیک اتخاذ شده توسط محققان ارائه شده‌اند. نتایج شبیه‌سازی موجود برای انرژی ساختمان‌های مسکونی نیز معرفی شده‌اند. این تحقیق قابلیت‌ها و عملکردهای شبیه‌سازی و مدل‌سازی Ecotect از جمله نور روز، تابش خورشیدی، آنالیز حرارتی و سایه‌زنی برای مدیریت انرژی و حفاظت از ساختمان‌های مسکونی را بررسی کرده است. روش‌های مختلف مدل‌سازی و شبیه‌سازی، از ساختمان‌ها و اقلیم‌های مختلف، بررسی و مورد بحث قرار گرفت. تجزیه و تحلیل کار حاضر کمک زیادی به تصمیم‌گیری محققین و انتخاب نرم‌افزار برای انجام شبیه‌سازی‌های مختلف در مدیریت انرژی ساختمان‌های مسکونی می‌کند.