Lighting Design and Energy Simulation of a Residential House

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Keywords: Simulation, Energy-Efficient, Dwelling, Insights, Modelling.

Abstract: Building Energy Simulation is a process for assessing and analyzing the building's energy performance. Building Energy Simulation (BES) helps in to designing energy-efficient and sustainable buildings. The main objective of BES is to predict the usage of energy in a building throughout its lifecycle. According to studies, the building consumes 40% of global energy, contributing to global warming and many other environmental causes.The lighting analysis of a single-family dwelling model is the main topic of the building energy simulation study. The goal is to employ first-form modeling to assess the energy usage and lighting system performance in a representative single-family home. The lighting study considers several variables, including fixture types, lighting settings, and the use of natural sunshine. The simulation model offers insights into trends in lighting energy usage, peak demand times, and potential energy-saving solutions. The study contributes to a better knowledge of lighting efficiency in single-family homes by evaluating the energy performance of the lighting system. The research findings can help with decision-making for improving lighting design, energy-efficient technology, and control methods to improve overall energy performance in residential buildings. This paper provides helpful insights for energy-efficient lighting design and decision-making in the residential sector by summarising the lighting study of a single-family house model using building energy simulation.

1 INTRODUCTION

Building Energy develops, engineers, builds, and runs projects as part of its vertically integrated renewable energy business. In 2010 in Milan, Italy, Building Energy was established. The corporation launched a venture in the solar sector with the goal of geographical and technological expansion [M. Neardey, 2019].

A simulation is an ongoing replica of how a system or process might work in the actual world. Models must be used in simulations; the model reflects the essential traits or behaviours of the chosen system or process, whilst the simulation depicts the model's development through time. Computers are frequently utilised to run the simulation [L. P Chung,2019].

Commercial, residential, and industrial buildings use more than three quads of energy, according to U.S. Energy Information Administration (Washington, DC, USA). By the year 2020, all US energy usage [Tobias Maile, 2007]. Thus, lowering energy use and creating buildings that are energy efficient is important for the development of nations. "BES aids in the optimization of designers!" evaluate a building's energy efficiency before it is built and aids in the development of extremely energy-efficient structures and the advancement of sustainability. A smart building designer mustcombine the demands for thermal and visual comfort with the environmental conditions that may vary dramatically during the year, such as air temperature, humidity, sun radiation, wind speed, and direction, etc. By simulating the building's energy performance under these situations, it is possible to find the best conditions that may vary dramatically during the year, such as air temperature, humidity, sun radiation, wind speed, and direction, etc. By simulating the

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Varshney, Y., Viral, R. and Asija, D.
Lighting Design and Energy Simulation of a Residential House.
DOI: 10.5220/0012504500003808

In *Proceedings of the 1st International Conference on Intelligent and Sustainable Power and Energy Systems (ISPES 2023)*, pages 15-23
ISBN: 978-989-758-689-7

building's energy performance under these situations, it is possible to find the best design options, control setups, and energy-saving measures. This information aids decision-makers in making choices on equipment selection, building envelope design, etc. It also aids in assessing the financial viability of various design options, energy-saving measures, and equipment upgrades. and improve reduced utility costs, decreased maintenance & operating costs.

A BEM program's inputs include information on a building's geometry, building materials, lighting, HVAC, refrigeration, water heating, renewable generation system configurations, component efficiency, and control techniques. It also collects information on how the building is used, such as descriptions of the lighting, plug loads, and thermostat settings as well as occupancy schedules.

1.2 Basic Principles of Energy Simulation

The energy efficiency of a specific structure and the thermal comfort of its occupants are predicted by BES tools [Tobias Maile, 2007]. We are all aware that the accuracy of the results generated by any simulation programme depends on the input data i.e. Building orientation, internal equipments loads, HVAC systems and parts, climate information, operational plans, and timetables make up the majority of the input. A BEM program's inputs include configurations, component efficiencies, and control strategies., as shown in Figure 1 which describes the complete simulation engine [Tobias Maile, 2007]. BES programmes use qualified equations and methodologies to approximate their predictions.

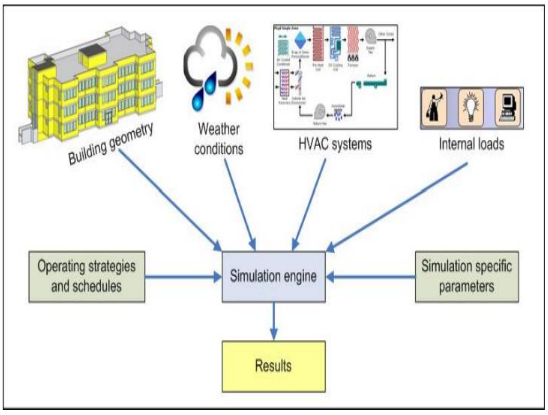

Figure 1: General Flow of Simulation Engine.

Table 1: Necessary data for Energy Modelling [Donald R. Wulfinghoff, 2010].

Category	Purpose	Source
Geographical Location	precise load calculations depending on the external environment	Weather file
Geometry • Plan • Section • Elevation	Model geometrical attributes of buildings and any site specific features (shading, reflection of trees or building)	Architectural drawings
Construction • Wall • Roof • Window • Overhangs	Calculating thermal load and daylighting using model building envelope attributes	• ECBC • ISHRAE • CBRI • ASHRAE
Daylighting and lighting • Layout • Technology and Controls	• Visual Comfort • Reducing LPD • Integration with daylight	• Lighting consultant • Vendors • ISLE/IES
Internal load • Usage • Schedule • People, equipment, lighting	Accurately capture sources of internal heat gains within building	• Client • Energy modeller • Benchmarking Data • Nameplate Data
HVAC (type and controls) • Component Specification • Control strategy • Layout and distribution	• Sizing the system • Design Optimization • Comfort satisfaction	• HVAC consultant • ASHRAE/ISHRAE • ARI • ECBC

1.3 Algorithm for Conduction of Building Energy Simulation

Building Energy Simulation procedure includes a number of processes to forecast a building's energy performance and pinpoint prospective upgrades. This summarizes all stage summaries, i.e.

Step 1: Data Gathering: The initial phase in the energy modelling process is to gather comprehensive data regarding the architecture, systems, and operations of the building [Garg Vishal, 2010].

Step 2: Choosing a Software Tool Consider the following aspects while choosing the appropriate tool for your project [Garg Vishal, 2010].

Step 3: Developing the energy model: Beginning the development of the energy model requires the

collection of data and the selection of a software tool [Garg Vishal, 2010].
Step 4: Reviewing and analyzing the results should include looking at things like energy usage, peak loads, comfort levels, etc [Garg Vishal, 2010].
Step 5: Refine and optimize: If the simulation does not get the desired results, then adjust the simulation's settings and repeat the procedure to see how it affects the building model [Garg Vishal, 2010].

Table 2: Application and Limitation of BES.

S.No.	Application	Limitation
1	Energy analysis of the entire building	Uncertainty in input data
2	Studies on daylighting and natural ventilation [Rawal Rajan,2010].	Making assumptions and simplifying complex situations
3	HVAC System Design [Martina Fischer, 2007]	Time Consumption
4	Retrofit Analysis	Complexity of modelling
5	Building Stock Study	Lack of data availability

2 LITERATURE REVIEW

Numerous case studies have been done to examine how well lighting uses energy in various building types, such as workplaces, homes, and educational facilities. These studies demonstrate how building energy simulation can be used to observe lighting energy use and guide the development of energy-saving strategies.

Here, I am using the single-family house for lighting analysis which consists of some equipment like a dishwasher, heater, television, etc., and analyzes the usage of electricity using graphs and tables.

Table 3: Literature Review.

Author(s)	Details	Remarks	Year
Donald R. Wulfinghoff, Rajan Awal, Vishal Garg	Energy Simulation provides a powerful tool for evaluating the energy performance of buildings and making informed design decisions. It allows us to explore different strategies and technologies to achieve energy efficiency and sustainability .	Explain the Building Energy Simulation process and develop an energy-efficient building.	2010
Joseph J. Romm	Energy simulation software allows the simulation of building systems including HVAC, lighting, and renewable energy integration .	Describe the simulation of all different loads.	2006
Michael E.Casper	simulation software allows for detailed analysis of lighting systems, considering factors such as fixture types etc .	Simulation help to make changes in building before construction.	2007
Dikshu C. Kukreja	Energy simulation software enables designer to evaluate different lighting design options and optimize	Energy Plus was developed by the US Department of Energy.	2001

	energy performance while maintaining visual comfort .		
Drury B. Crawley	Building Energy Simulation provides a powerful tool for evaluating the energy performance of buildings and making informed design decisions. It allow us to explore different strategies and technologies to achieve energy efficiency and sustainability.	Building energy simulation is the compass that points architects and engineers towards a greener, more sustainable future.	2003
Subrato Chandra	When evaluating energy retrofit options, energy simulation software provides the valuable tool for assessing in the potential energy savings and payback periods of various measures.	Simulation software serves as the financial and environmental compass for energy retrofits, pointing us in the direction of cost savings and sustainability.	2005

3 BUILDING ENERGY SIMULATION TOOLS

Computer programmes for simulating building energy use can be thoroughly analyzed using computer-based simulation software, which is designed to do this. Buildings typically employ about one-third of their total head space for lighting and improving the thermal conditions of the homes. Designers today require technologies that provide answers to highly specific questions very early in the design process. Software for simulating energy can help designers think through certain options. Additionally, designers can replicate the cost of energy in existing buildings under their current conditions and provide the thermal behavior of buildings prior to their construction. The following variable can also be calculated using software tools in addition to energy consumption modelling [Dikshu C. Kukreja,2001].

3.1 Energy Plus

Energy Plus (Version 2.1) creates a "new generation" simulation engine, seen in Figure2, by combining the best elements of the DOE-2 and BLAST energy simulation engines. Users of the programme Energy Plus may simulate the energy use of a whole building as well as model their own water and energy use. It is a text-based programme that runs on a console and reads input and output. A variety of tools are included with it, including IDF-Editor, which has a straightforward spreadsheet-like user interface for producing input files. It is a straightforward data-in, data-out programme, but it has a few graphical user interfaces to make it simpler to use. The American Department of Energy is funding the initiative[Subrato Chandra, 2005].

Energy Plus is based on an integrated (loads and systems modeling) methodology, which yields better estimates of many outcome factors, such as thermal comfort and more precise predictions of temperature in spaces. The preferred heat-balanced-based methodology of AHSRAE is used in the load calculations [Tobias Maile, 2007].

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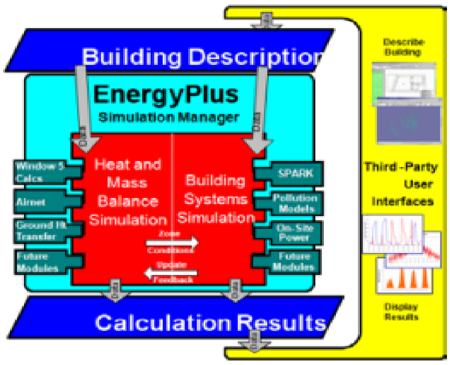

Figure2: The Program Structure of Energy Plus [Tobias Maile, 2007].

Due to streamlined management schemes and idealized HVAC components, Although there are significant limitations during building operation, Energy Plus enables the flexibility and capability to be used throughout the whole life cycle of a structure.

3.2 eQuest

One of the most often utilised energy modelling tools throughout the early stages of design is eQuest. Its full name, rapid Energy Simulation Tool, inspired its moniker, and it truly is a very rapid way to do energy simulations. James J. Hirsch & Associates created the programme with assistance from the US Department of Energy. [Subrato Chandra, 2005].

The so-called Schematic Design (SDW) and Design Development Wizards (DDW) are two of the design wizards offered by eQUEST. Both depict recognisable design phases, albeit the amount of detail in each varies greatly. Data entry may be made simpler by using the default parameters of both wizards.

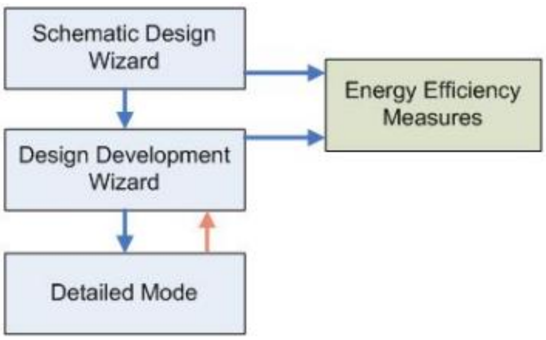

Figure 3: Wizards in eQUEST.

As depict in Figure 3, It is possible to switch between less-detailed wizards and more-detailed explanations of the structure. The detailed mode, which allows all accessible parameters to be set and modified in accordance with definitions found in the DOE-2 engine, is the fundamental idea behind eQUEST. Another feature of this tool is the Energy-Efficiency Measures, which permit quick differentiation of particular input parameters (such as capacity values of a coil). Almost all of the parameters that are provided in the wizard can be changed using this tool although it can only be used in SDW or DDW mode, is a comparable wizard.

It offers two options for importing CAD programme building geometry data. Both are based on gbXML, one on DWG format. Figure 4 depicts both of them.

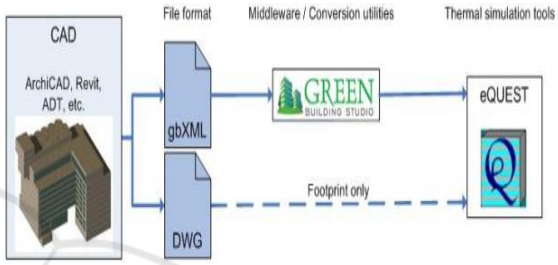

Figure 4: Data exchange capabilities of eQUEST.

3.3 Open Studio

Open Studio is an open-source "collection of software tools to support whole building energy modeling using Energy Plus and advanced daylight analysis using Radiance." The National Renewable Energy Laboratory, a division of the United States Department of Energy, produced the project [Subrato Chandra, 2005]. Both a Command Line Interface (CLI) and a Software Development Kit (SDK) are components of the Open Studio SDK. The application programming interface (API) provided by the Open Studio SDK theoretically allows access to the Energy Plus modelling engine [Drury B. Crawley, 2003]. This interface offers a variety of advantages, including a robust, version-controlled interface, space typology abstractions that make it simpler for end users to model buildings, and language bindings in Ruby, Python, and C-Sharp that make it more accessible to users acquainted with these languages. Support for large-scale analysis, such as design optimisation, model input calibration, building stock analysis to identify buildings that are suitable for particular programmes, or prototype analysis to create typical savings figures, is one area of concentration for the Open Studio project.

Table 4: Review of building energy software tools.

Tools	Characteristics	Merits	Demerits
Energy Plus	• Inputs: Extensive summary • Outputs: Text, IDF/IDD • GUIs: Use 3rd party GUIs • Algorithms: Surface heat balance; Zone air heat balance. • Timesteps: 1 to 60 minutes • Weather Data: Hourly or sub-hourly • User Customization: EMS (Energy Management System), External Interface • Copyright: Open source • Language: Fortran	• Comprehensive modelling • Hourly time step analysis • Climate-specific simulation • Parametric simulations • Detailed component modelling • Thermal comfort analysis • Renewable energy integration • Open-source and extensible Large user community	• Complexity • Steep learning curve • Command-line interface • Computational resource requirements
eQUEST	• Inputs: Template based • Outputs: Standardized • GUIs: Template based • Algorithms: Calculation based • Timesteps: Pre-defined • Weather Data: Pre-selected • HVAC: Template driven • User Customization: Limited • Copyright: Proprietary • Language: English	• Template-based interface • Whole-building energy simulation • HVAC system analysis and optimization • Parametric simulations • Compliance with energy codes and standards • Economic analysis and life-cycle cost optimization • Detailed energy consumption breakdown • Reporting and results visualization	• Limited flexibility • Reliance on pre-defined templates • User interface may not be intuitive for complex simulations • Limited availability of user support and community
Open Studio	• Inputs: Customizable • Outputs: Versatile • GUIs: Graphical • Algorithms: Scripting • Timestep: Flexible • Weather data: Extensive • HVAC: Detailed • User customization: Extensible • Language: Ruby	• Graphical interface • Integration with Energy Plus • Component-based modeling • Parametric simulations • Whole-building energy simulation • HVAC system design and optimization • Daylighting and shading analysis • Reporting and results visualization • Workflow automation	• Learning curve • Plugin dependencies for certain features • Limited availability of pre-defined templates • Limited user community and support compared to larger software platforms

4 RESULTS AND ANALYSIS

The file which is used for simulation whose name is single-family house, I referred the file from Energy Plus Software basics file [Joseph J. Romm, 2006].

In this section, we will analyze only the lighting load case in an input IDF file whose name is Single Family House.

In this house, we define building construction, geometry, schedule, etc. Here, we use the refrigerator, dishwasher, fans, etc. In this file, we define many parameters but discuss only parameters responsible for lighting load. In this simulation, we use the weather file of New Delhi which is available on the Energy Plus official website.

Now, we edit the input IDF file of the building by clicking the edit IDF Editor. After editing the file, click on simulate button and the simulation screen is pop- up on the screen.

Now, we use pictures and graphs of data which we get after simulation in HTML form from HTML file as shown in Tables 5,6,7 and Figure 5,6,7.

Here, Table 5 as well as Figure 5 shows the data which come after the simulation of the domestic building which explains how much site and source energy is used in this domestic building.

Total site energy in a building refers to the complete energy consumption encompassing all energy sources and end uses associated with the building and its operations. It includes the energy used for heating, cooling, lighting, plug loads, and other building systems.

Net site energy in a building refers to the energy consumed by the building from external sources, minus any energy generated on-site through renewable or alternative energy systems. It represents the actual energy that needs to be supplied from external sources to meet the building's energy demands.

Net source energy in a building refers to the total energy consumed by the building, accounting for both the energy consumed on-site and the energy required for the production, transmission, and distribution of the energy from primary sources.

Total source energy in a building is the total amount of energy used during the course of the building's full life cycle, including the energy utilized inside the structure as well as the energy needed for the extraction, processing, and delivery of all energy sources.

This data explain the total energy usage of total site energy, net site energy, total source energy, and net source energy in this domestic building.

Table 5: Site and Source Energy Data.

	Total Energy [kBtu]	Energy Per Total Building Area [kBtu/ft2]	Energy Per Conditioned Building Area [kBtu/ft2]
Total Site Energy	4118.24	1.15	1.73
Net Site Energy	4118.24	1.15	1.73
Total Source Energy	13042.48	3.66	5.49
Net Source Energy	13042.48	3.66	5.49

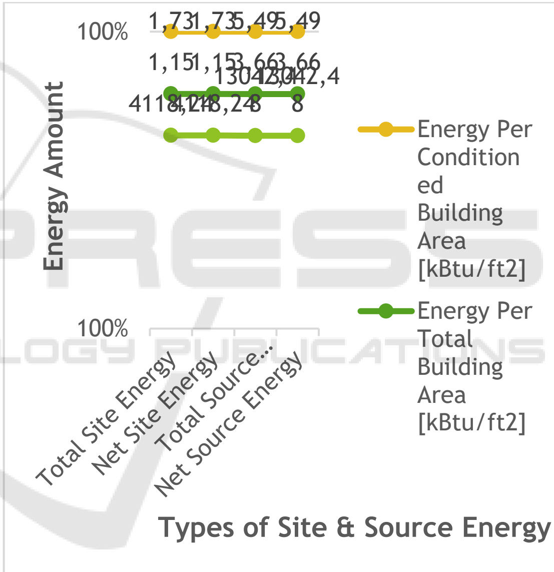

Figure 5: Relation b/w Site and Source Energy.

Table 6: Interior Lighting Load Data.

	Zone Name	Lighting Power Density [Btu/h-ft2]	Total Power [Btu/h]	Full Load Hours/Week [hr]	Consumption [kWh]
LIVING HARDWIRED	LIVING_UNIT1	0.3335	792.73	58.88	60.58

LIGHTING1					
LIVING PLUG-IN LIGHTING1	LIVING_UNIT1	0.1517	360.49	58.88	27.55
Interior Lighting Total		0.2426	1153.22		88.13

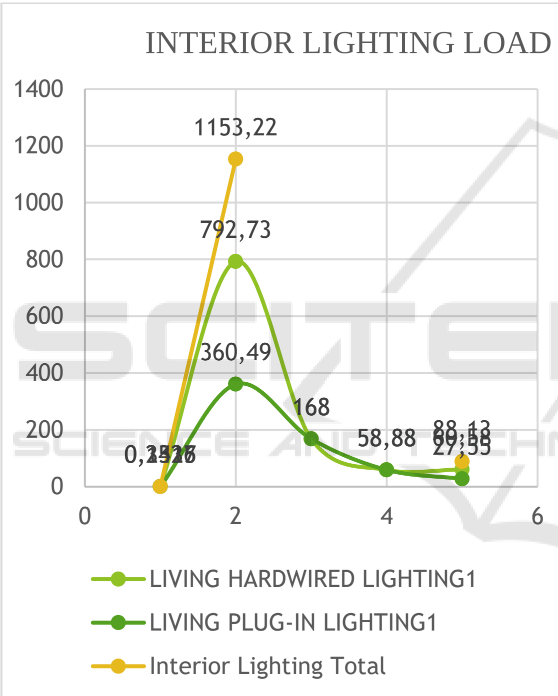

Figure 6: Interior Lighting Load.

Table 7: Exterior Lighting Load Data.

	Total Watts	Full Load Hours/Week [hr]	Consumption [kWh]
EXTERIOR-LIGHTS_UNIT1	43.24	84	16.09
GARAGE-LIGHTS_UNIT1	7.16	58.88	1.87
Exterior Lighting Total	50.41		17.95

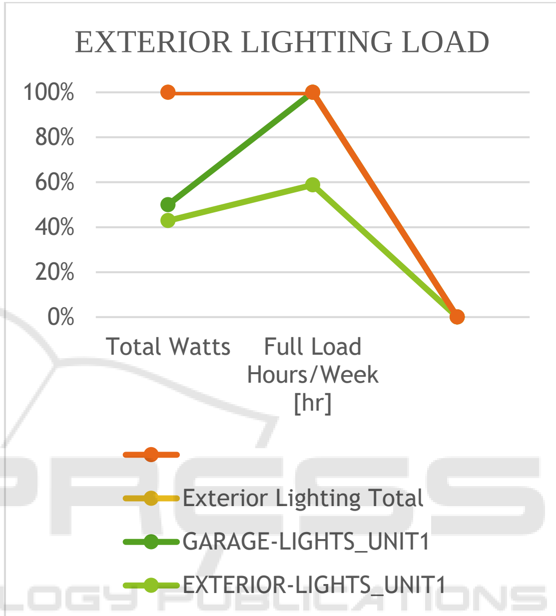

Figure 7: Exterior Lighting Load.

5 CONCLUSION

The lighting case analysis showed that building energy simulation is a useful tool for assessing and improving the energy performance of buildings. Energy simulation software was used in the lighting case analysis to provide a thorough evaluation of the energy usage, effectiveness, and effects of the lighting system on the entire facility.

The investigation emphasized how crucial it is to take lighting design and control strategies into account early on in the building design process. It was possible to determine the most energy-efficient lighting systems while preserving the desired illumination quality and occupant comfort by modelling various scenarios.

In conclusion, the building energy simulation carried out by the software Energy Plus using graphs depicting the lighting loads in residential structures offers important insights into the patterns of lighting energy use. This analysis provides a solid basis for making judgements on lighting design, energy-efficient lighting systems, and methods for improving the efficiency of energy use in residential buildings. We can design sustainable and energy-efficient structures using the simulation.

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