

Influence of Building Orientation on Instant, Delayed Sensible and Latent Energy Loads: A Building Information Modelling (BIM) Based Analysis

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DOI: <https://doi.org/10.30880/ijscet.2025.16.01.004>

Article Info

Received: 22 November 2024
Accepted: 12 June 2025
Available online: 30 June 2025

Keywords

Orientation, instant, delayed sensible, latent, energy load, BIM

Abstract

The orientation of a building plays a crucial role in its energy performance, affecting both immediate and delayed thermal responses. The influence of instant, sensible, and latent energy loads on a building is a critical aspect of understanding and optimizing its energy performance. These three components play a crucial role in shaping the thermal dynamics and overall energy consumption of a structure. Building Information Modelling (BIM) offers a sophisticated framework for analysing and simulating these intricate relationships, providing a comprehensive understanding of the dynamic interplay between building orientation and energy loads. BIM represents a holistic digital representation of a structure, encompassing not only its geometric attributes but also the intricate interplay of spatial relationships, material characteristics, and performance parameters. The research employs BIM-based simulations to evaluate the instant, delayed sensible, and latent energy loads associated with different building orientations at 0°, 45°, 90°, 135° and 180°. By leveraging BIM's capabilities in integrating diverse building parameters and environmental factors, the study aims to unravel the nuanced interactions that contribute to energy consumption patterns. Through this approach, the research contributes valuable insights into optimizing building design for enhanced energy efficiency. The findings of this study have practical implications for architects, designers, and policymakers involved in the construction and retrofitting of buildings. By delineating the influence of orientation on energy loads, the research aids in informed decision-making, promoting sustainable practices in building design and operation. This BIM-based analysis offers a robust methodology for assessing and optimizing energy performance, contributing to the ongoing discourse on environmentally conscious and energy-efficient building practices.

1. Introduction

The imperative pursuit of sustainable and energy-efficient architectural design has assumed an ever-escalating prominence within the dynamic realms of architecture, engineering, and construction. This exigency is further

underscored by the disconcerting statistic that more than one-third of global energy consumption and carbon emissions can be directly ascribed to the multifarious activities surrounding the construction of buildings [1]. Evidently, this exigency finds substantial resonance within the United States, where a report from the [2] delineates that an astounding 41% of the nation's energy usage can be traced back to the confluence of the building industry and its ensuing operational facets. Furthermore, it is imperative to discern that, as elucidated by [3], the operational phase of a building's lifecycle exacts a pronounced energy toll, accounting for an overwhelming 87% of the total energy consumption in both the United States and Europe. This disquieting reality reaffirms that the operational epoch of a building's existence is now poised to acquire a heightened focus, driven by an urgent need to ameliorate its deleterious environmental consequences. In this critical context, the instrumental role of energy simulation in prognosticating energy performance and optimizing both the design and operations of structures becomes manifest. As the global imperative to grapple with environmental exigencies and the imperative of judicious resource utilization intensifies, experts within the Architecture, Engineering, and Construction (AEC) sector are diligently exploring avant-garde methodologies. Building Information Modelling (BIM) energy analysis emerges as one such venerable technique that has garnered widespread recognition. BIM represents a holistic digital representation of a structure, encompassing not only its geometric attributes but also the intricate interplay of spatial relationships, material characteristics, and performance parameters. The integration of energy analysis into the design and decision-making processes empowers professionals to make judicious, data-driven choices that engender more economical, efficient, and ecologically sustainable structures. As a tangible exemplification of this paradigm, an academic inquiry [4] embarked on the simulation and subsequent redesign of an extant building, employing the formidable capabilities of BIM technology. The study meticulously scrutinized diverse design options for the building envelope and elucidated their profound influence on the BIM tool's capacity to effect energy conservation. It is quintessential to acknowledge that the utilization of BIM as a methodological framework, coupled with its attendant technologies, holds the potential to significantly augment the efficiency and effectiveness of a project from its nascent conception to its enduring operation and maintenance. A study denoted as [5] underscores the invaluable role that Building Information Modelling (BIM) plays in enhancing the comprehension of how a structure's orientation impacts its energy consumption, particularly beneficial for small-scale builders. This illuminates the practical utility of BIM in refining the understanding of energy dynamics in the realm of construction. Meanwhile, study [6] delves into the intricate realm of system interfaces bridging BIM and energy simulation. These interfaces enable the semi-automated conversion of building models from BIM to Building Energy Modelling (BEM). This symbiotic relationship between BIM and energy simulation fosters a more streamlined and efficient transition, expediting the translation of architectural concepts into energy-efficient building models. Moreover, the intrinsic strength of BIM lies in its ability to harmonize and consolidate information within a collaborative and shared data environment.

The energy performance of a building is determined by how much energy is used or estimated to meet the various needs associated with a standardized use of the building. These needs may include solid-state lights, grid-collaborative effective buildings, sensing devices and controls, HVAC, water heating, applications, windows, and building envelope [7]. Building energy models are often developed independently of building information models, and a separate analytical tool is used for energy analysis [8]. Serious issues include redundant data processing and storage, error-prone data duplication, and data leakage in the traditional method of evaluating energy performance, which involves designers manually simulating an energy model [9]. Using pre-existing BIM data to produce the building energy model expedites the process, and employing several analysis tools makes sense. Numerous studies have been conducted on the primary benefits and added value of using BIM to increase energy efficiency in the energy sector [5], [10], [11], [12], [13], [14], [15]. However, little concentrated study has been done using simulation and analysis in the areas of optimal design and energy load component assessment based on BIM. Upon reviewing prior research, it is evident that no studies have been conducted to investigate the assessment of energy and heat loads through the simultaneous evaluation of building components using BIM technology, conceptual design approach, and comparison based on building orientation. Hence, an important component of this work is figuring out how building orientation affects a building's energy loads like latent, delayed sensible, and instantaneous heat loads. This influence is pivotal in the quest for optimizing energy consumption and reducing the carbon footprint of a built infrastructure [16], [17], [18], [19], [20], [21], [22], [23]. The instant heat load represents the immediate energy requirements for heating or cooling a building, influenced by factors such as the building's orientation, window placement, and insulation. Understanding how building orientation affects this load can lead to more efficient HVAC system designs and substantial energy savings. The delayed sensible load pertains to the thermal inertia of a building, including the heat absorbed or released by its structure and materials over time. Orientation plays a pivotal role in determining how quickly a building can adjust to temperature fluctuations, which is crucial for maintaining comfortable indoor conditions and reducing energy consumption. Lastly, the latent load considers the moisture-related energy demands within a building. It is affected by factors like ventilation rates, building occupancy, and materials used. Investigating how the building orientation influences this load can further help in designing ventilation systems that optimize indoor air quality while minimizing energy consumption.

As delve into this study, involves leveraging the power of BIM to model and simulate various architectural configurations and their associated energy performance. Through a thorough examination of these key elements, the research aims to provide valuable insights into the potential for energy-efficient building designs that not only reduce operating costs but also contribute to a more sustainable and environmentally responsible future. By shedding light on the intricate relationship between architectural geometry and building energy loads, this research seeks to offer practical guidance to architects, engineers, and other stakeholders involved in the design and construction of energy-efficient buildings.

2. Building up Energy Model & Simulation Methodology

2.1 Software Selection

For a number of reasons, Autodesk Revit 2020 was selected to develop the building information model. First, Autodesk Revit offers a number of methods for creating models through top-down or bottom-up design approaches. Two, energy analysis may also be done within the Autodesk Revit software by using the Autodesk Insight plugin. Three, the ability to export building data in common formats like gbXML and IFC, which enables the use of other energy analysis applications to perform energy analysis. This study used relevant energy-related techniques to conduct energy analysis. The speed with which this tool can produce an energy model and visualization during the first stages of design led to its selection.

2.2 Project Setup

A detailed 3D model of academic building was created, including walls, windows, doors roofs and other building components. The area and volume of the building was 70076.89 sq. ft and 770965 cubic ft. respectively. The building geometry was changed about an angle of 45°, 90°, 135°, 180°, 225° and 360° for their respective simulation performance analysis.

Table 1 Project setup

Building Type	Academic building
Location	Rajshahi, Bangladesh
Air Temperature	68° F
Radiant Temperature	63.85° F
Operative Temperature	65.93° F
Outside dry-bulb Temperature	39.02° F

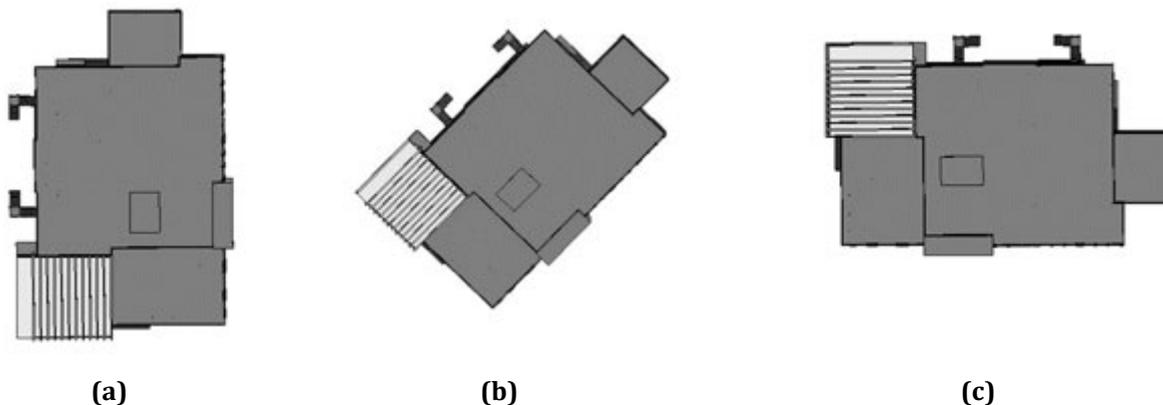


Fig. 1 3D model of building

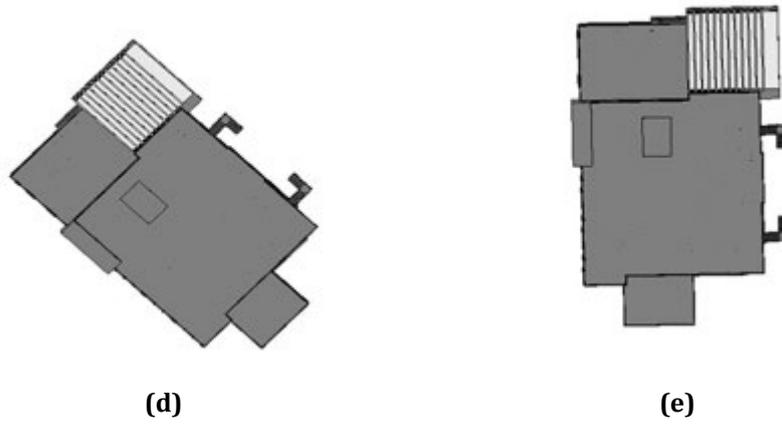


Fig. 2 Building orientation (a) 0°; (b) 45°; (c) 90°; (d) 135°; (e) 180°

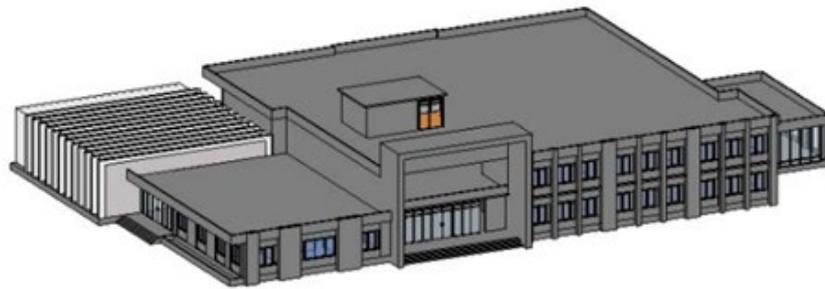
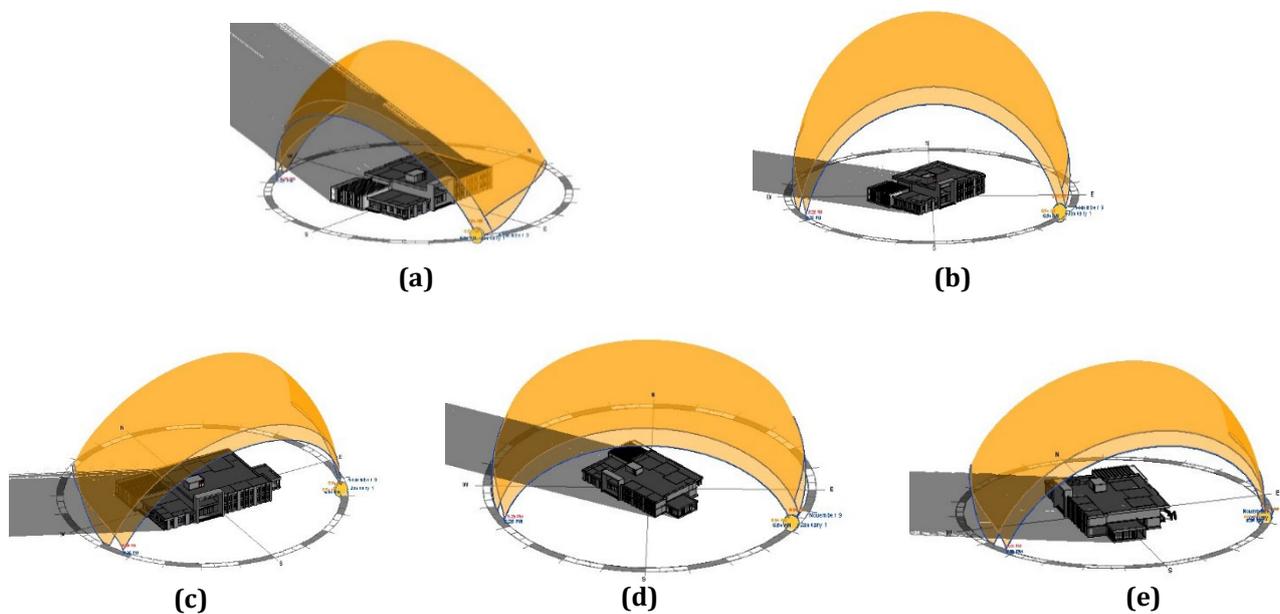


Fig. 3 Sun path analysis (a) 0°; (b) 45°; (c) 90°; (d) 135°; (e) 180°

2.3 Solar Orientation Study

This study looks into the effects of different orientations on building surfaces and solar radiation. A graphical representation of solar radiation will be produced after setting parameters such the project location, date, time, and interval. This will show that the south-eastern side is oriented at 0°, the eastern side at 45°, and the north-east side at 90°, north side at 135° and north-western side at 180° orientation received the most sunlight.



2.4 Defining Building Elements

Detailed information about materials, insulation, glazing, and other relevant building components was included along with modelling the HVAC systems, lighting, and other energy-related systems within the building. It was ensured that the building's architectural and MEP (Mechanical, Electrical, Plumbing) elements are accurately modelled in the Revit project. The built-in Energy Analysis tools in Revit was used to analyse the energy consumption of the building. This can be found under the "Analytical Model" tab. The energy analysis parameters were specified including building type, occupancy, and usage patterns. After modelling and adjusting the parameters required in Autodesk Revit software (Table 2), was created an energy model using the analyze tab. Then, an Autodesk account was used to send the energy model to Autodesk Insight Software and receive the data analysis results.

Table 2 Defining the building elements in Insight 360 software

Input Parameter	Current Setting
Building Orientation	BIM
WWR (S)	15%
Window Glass	BIM (Double Pane Clear – No Coating) * Trp LoE**
WWR (N)	BIM (30%)
Window Shades(N)	2/3 Win Height**
Window Glass	BIM (Double Pane Clear – No Coating) * Trp LoE**
WWR (W)	BIM (15%) *
Window Shades(W)	2/3 Win Height**
Window Glass	BIM (Double Pane Clear – No Coating) * Trp LoE**
WWR (E)	BIM (17%) *
Window Shades	2/3 Win Height**
Window Glass	BIM (Double Pane Clear – No Coating) * Trp LoE**
Wall Construction	12.5inch SIP
Roof Construction	BIM
Infiltration	0.4 ACH**
Lighting Efficiency	7.53 W/m ²
Daylighting and Occupancy Controls	Occupancy Control
Plug Load Efficiency	10.76 W/m ²
HVAC	High Efficiency Package System
Operating Schedule	12 hours
Panel Efficiency (PV)	20.4%
Payback Limit (PV)	30 years
Surface Coverage (PV)	90%

2.5 Analysing The Model

The intrinsic Energy Analysis tools embedded within Autodesk Revit 2020 served as the instrumental conduit for a comprehensive examination of the building's energy consumption dynamics. Situated adeptly under the "Analytical Model" tab, these sophisticated tools provided an intricate platform for scrutinizing and unravelling the intricate facets of the structure's energy utilization. In the pursuit of a nuanced understanding, meticulous attention was devoted to configuring the energy analysis parameters within the software interface. Under the umbrella of the "Analytical Model" tab, the nuanced intricacies of the building were methodically delineated,

encompassing pivotal aspects such as building type, occupancy considerations, and the intricacies of usage patterns.

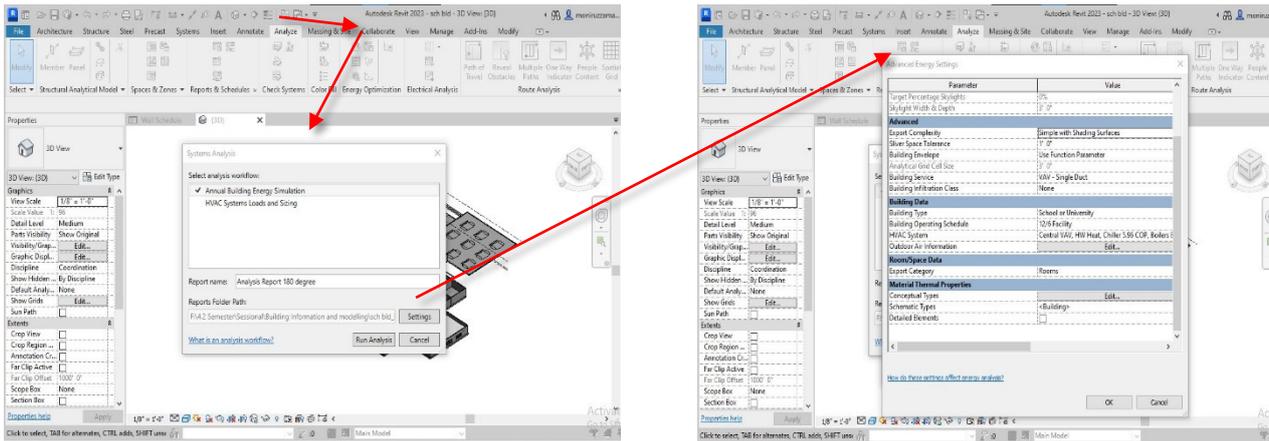


Fig. 4 Analysis tool in Revit software

2.6 Simulation and Performance Evaluation

After setting up all the parameters followed by climate and solar orientation analysis, initial energy simulations and analyses were performed to evaluate the building's energy load component. After that design adjustments based on the initial energy analysis results were made to building geometry at the angles of 0°, 45°, 90°, 135° and 180 and energy simulations were re-run to assess the impact of design changes on energy load components.

3. Simulation Result

In the realm of building performance analysis, the examination of simulation results stands as a pivotal tool for unravelling the intricacies of a structure's energy efficiency. Within the confines of this analysis, the data presented in the table meticulously details the various zones considered within the building. This breakdown provides a nuanced understanding of the load distribution within each zone. This comprehensive evaluation delves into a myriad of factors, with a primary focus on understanding heating and cooling loads. These loads, further classified into Instant Sensible, Delayed Sensible, and Latent Heat Load, bear dependencies on the building envelope, internal gains, and the intricate web of integrated systems. A noteworthy observation surfaces as the heat load for the building envelope consistently registers as negative across all orientations. This negative trend signifies a pervasive heat loss through the building envelope. In stark contrast, the heat gain experienced is attributed to internal gains and the synergistic operation of integrated systems. The following table-3,4,5,6 and 7 show the energy load summary for 0°, 45°, 90°, 135° and 180° respectively.

Table 3 Energy load summary 0° orientation

0 °	Instant Sensible			Delayed Sensible			Latent			Total
	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	
Envelope	92984	-42457	50527	1131	-165117	-163986	8708	10317	19025	-94434
Gains	1638733	0	1638733	769478	0	769478	574974	0	574974	2983185
Systems	1147411	-252646	894765	0	0	0	324874	129396	454270	1349035
Total	2879128	-295103	2584025	770609	-165117	605492	908556	139713	1048269	4237786

Table 4 Energy load summary 45° orientation

45 °	Instant Sensible			Delayed Sensible			Latent			Total
	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	
Envelope	87858	-42468	45390	-428230	-163774	-592004	14320	10333	24653	-521961
Gains	1613501	0	1613501	1172666	0	1172666	565974	0	565974	3352141
Systems	1105740	-248779	856961	0	0	0	459593	127635	587228	1444189
Total	2807099	-291247	2515852	744436	-163774	580662	1039887	137968	1177855	4274369

Table 5 Energy load summary 90° orientation

90 °	Instant Sensible			Delayed Sensible			Latent			Total
	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	
Envelope	108263	-42428	65835	-104363	-164721	-269084	25786	10318	36104	-167145
Gains	1612677	0	1612677	759112	0	759112	594845	0	594845	2966634
Systems	1126416	-251178	875238	19663	0	19663	454778	128752	583530	1478431
Total	2847356	-293606	2553750	674412	-164721	509691	1075409	139070	1214479	4277920

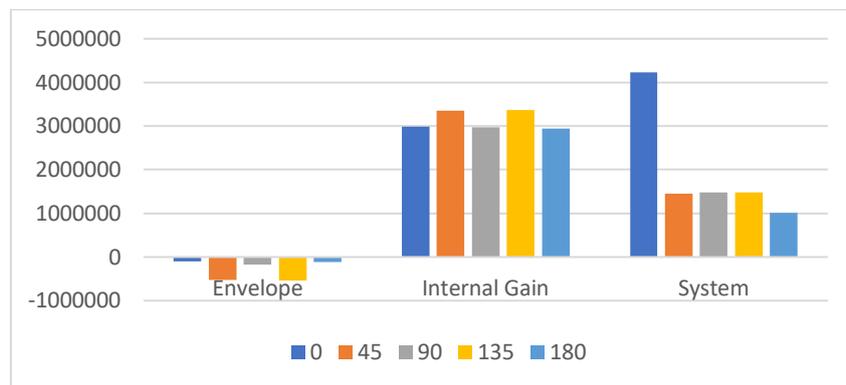
Table 6 Energy load summary 135° orientation

135 °	Instant Sensible			Delayed Sensible			Latent			Total
	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	
Envelope	110899	-42436	68463	-483693	-165385	-649078	26806	10343	37149	-543466
Gains	1615480	0	1615480	1181233	0	1181233	566774	0	566774	3363487
Systems	1153694	-249066	904628	11303	0	11303	436231	128022	564253	1480184
Total	2880073	-291502	2588571	708843	-165385	543458	1029811	138365	1168176	4300205

Table 7 Energy load summary 180° orientation

180 °	Instant Sensible			Delayed Sensible			Latent			Total
	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	Cooling	Heating	Cooling +Heating	
Envelope	89887	-42400	47487	-21856	-164819	-186675	8686	10323	19009	-120179
Gains	1618856	0	1618856	761173	0	761173	567819	0	567819	2947848
Systems	1134580	-251577	883003	0	0	0	321568	128909	450477	1011912
Total	2843323	-293977	2549346	739317	-164819	574498	898073	139232	1037305	4161149

A graphical representation of this phenomenon as shown in fig. 5 underscores the variations in heat loss for different orientations. Remarkably, the maximum heat loss manifests at 135 °s, while the least is discerned at 0 °s. Simultaneously, the internal heat gain demonstrates fluctuations, attaining its zenith at 135 °s and reaching its nadir at 180 °s. Digging deeper into the results, the system load analysis unfolds a compelling narrative. The 180° orientation emerges as the paragon of efficiency, boasting the least load at 1011912 btu/hr. In stark contrast, the 0° orientation presents a counterpoint, showcasing the maximum load at 4237786 btu/hr.

**Fig. 5** Energy load distribution in terms of envelope, internal gain and system

3.1 Instant Load, Delayed Sensible and Latent Energy Load Distribution

The heating and cooling loads generated from the building envelope, internal heat gains, and HVAC systems are categorized into three distinct components: Instant Sensible, Delayed Sensible, and Latent Heat loads. This categorization helps to provide a brief understanding of how energy loads behave under different building orientations. A detailed analysis reveals that Instant Sensible Load dominates the total energy load distribution across all orientations. Specifically, it constitutes 61.27% at the 180° orientation and 58.86% at the 45° orientation, showcasing its significant influence. This trend indicates that a substantial portion of the heating and

cooling requirements stems from immediate thermal gains and losses through the building envelope. In contrast, the Delayed Sensible Load exhibits a more intricate distribution pattern. It peaks at the 0° orientation with a contribution of 14.28%, suggesting delayed thermal effects from internal gains or envelope materials. Conversely, the lowest delayed sensible load occurs at the 90° orientation, accounting for 11.91% of the total energy load. This variation could be attributed to differences in solar exposure and thermal lag at different orientations. The Latent Heat Load, which is associated with moisture management, demonstrates a distinct pattern compared to the sensible loads. It reaches its maximum contribution at the 90° orientation, potentially due to higher humidity or ventilation interactions at this angle. Conversely, the latent load is minimal at the 0° orientation, indicating reduced moisture management demands. These variations are clearly illustrated in Fig. 6, where the radar chart provides a visual representation of the proportional contributions of each load type across orientations.

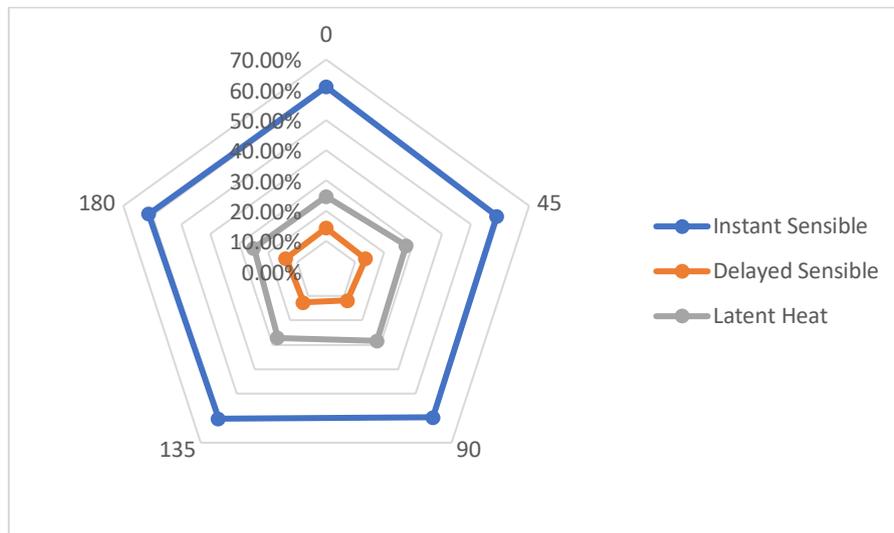


Fig. 6 Instant load, delayed sensible and latent energy load distribution

3.2 Total Energy Load

The overarching objective of this analysis is to fathom the total energy load, a metric derived from the summation of Instant Sensible, Delayed Sensible, and Latent Heat Load. The holistic Fig. 7 that emerges portrays the 180° orientation as the epitome of energy efficiency, boasting a total load of 4161149 Btu/hr. Conversely, the 135° orientation paints a less favourable picture, presenting a maximum total energy load of almost 4300205 Btu/hr. Hence, the results point towards the 180° orientation as the most favourable, offering potential avenues for further design and operational enhancements.

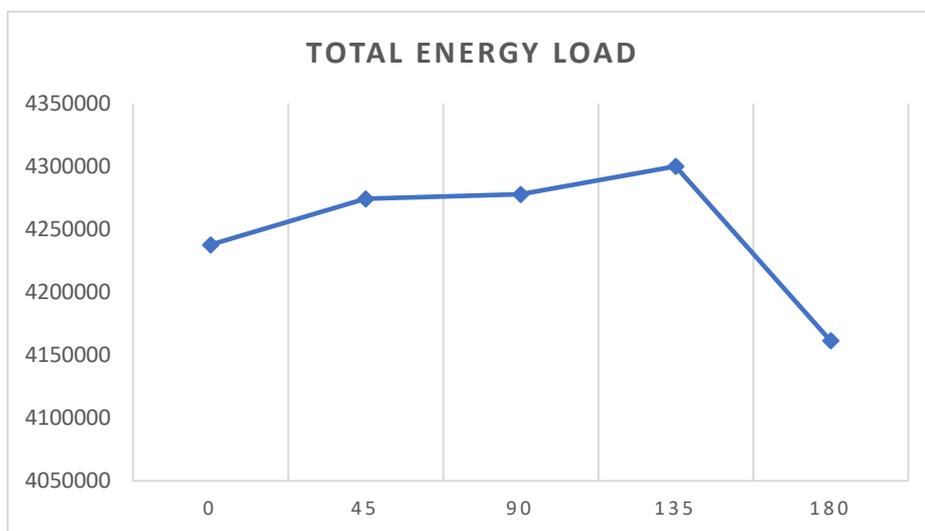


Fig. 7 Total energy load for different orientations

4. Significant Findings and Research Contributions

This study provides several significant findings that contribute to the understanding of building energy performance:

- Building orientation directly influences instant energy loads by affecting solar heat gain, window placement, and shading.
- Buildings oriented at 0° and 180° experience higher instant energy demands due to increased solar exposure.
- Delayed sensible loads are significantly influenced by a building's thermal inertia.
- Orientations at 45° and 135° optimize heat retention and release patterns, improving overall energy efficiency.
- Building orientation impacts moisture control and indoor air quality.
- Structures aligned to prevailing wind directions and equipped with optimal shading systems exhibit reduced latent loads and enhanced ventilation efficiency.

5. Recommendation

5.1 Orientation Matters: A Fundamental Determinant

Buildings with thoughtful orientation can capitalize on passive heating or cooling opportunities, significantly mitigating the reliance on active HVAC systems. This, in turn, has profound implications for energy consumption over time, emphasizing the need for a holistic approach to design that considers both short-term and long-term energy dynamics.

5.2 Latent Load Insights: Humidity Control and Indoor Air Quality

The research also delves into the latent energy loads associated with humidity control and indoor air quality. Building orientation plays a crucial role in influencing natural ventilation patterns and moisture accumulation. By aligning structures to prevailing wind directions and optimizing shading elements, designers can enhance airflow, reduce latent loads, and improve overall indoor environmental quality.

5.3 BIM as a Catalyst for Informed Decision Making

The integration of Building Information Modelling emerges as a catalyst for informed decision-making throughout the design and construction phases. BIM facilitates a holistic understanding of a building's performance, allowing stakeholders to simulate and analyse various orientation scenarios. This not only streamlines the design process but empowers professionals to make data-driven decisions that align with sustainability goals.

6. Conclusion

The study embarked upon a comprehensive investigation into the impact of building orientation on instant, delayed sensible, and latent energy loads, employing a cutting-edge approach grounded in Building Information Modelling (BIM). In the tapestry of building energy performance, this meticulous analysis unveils a nuanced interplay of factors, emphasizing the critical role of orientation in influencing a structure's energy efficiency. The simulation results, meticulously analysed, offer valuable insights into the energy performance of the building across various orientations. Envelope characteristics, internal gains, and system integration emerge as critical factors that demand attention in the quest for optimized energy efficiency. The emphasis on iterations in terms of angular orientation before constructing a building opens up potential avenues for further design and operational enhancements. Crucially, the study underscores the power of leveraging BIM tools in the hands of designers and architects. These tools not only facilitate a deeper understanding of a building's performance but also enable the simulation and analysis of diverse orientation scenarios. This data-driven approach empowers professionals to make informed decisions, aligning design choices with sustainability goals and reducing overall energy consumption. While the study provides valuable insights, certain limitations must be acknowledged. The research focuses on specific orientations (0°, 45°, 90°, 135°, and 180°), and additional orientations along with varied climatic conditions could provide a more comprehensive understanding. The simulation assumes uniform material properties and simplified geometries, which may not fully reflect the complexity of real-world structures. Looking ahead, the insights gleaned from this analysis should function as a guiding beacon for industry professionals committed to creating buildings that seamlessly blend with both nature and human needs. The call to action is clear – by prioritizing proper orientation through the lens of BIM, architects and designers can optimize building performance, contribute to a more resilient built environment, and play a pivotal role in fostering a sustainable future. As conclude our investigation, the nuanced interplay of factors influencing a structure's energy

efficiency becomes increasingly apparent. The findings from this comprehensive analysis serve as a cornerstone for design refinements and operational optimizations, providing stakeholders with a roadmap towards more sustainable and resource-conscious building practices. In the dynamic landscape of architecture, where each decision echoes through the lifespan of a structure, this study champions the cause of thoughtful orientation, asserting its significance in the pursuit of energy-efficient and environmentally conscious buildings.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

Conceptualization, Muhammad Moniruzzaman, Aninda Ghosh Partha and Faruque Abdullah; **Data curation**, Muhammad Moniruzzaman; **Formal analysis**, Md Rabiul Hasan and Faruque Abdullah; **Methodology**, Muhammad Moniruzzaman and Aninda Partha; **Software**, Muhammad Moniruzzaman; **Supervision**, Faruque Abdullah; **Writing – original draft**, Muhammad Moniruzzaman, Aninda Ghosh Partha and Md Hasan; **Writing – review & editing**, Aninda Ghosh Partha, Md Rabiul Hasan and Faruque Abdullah.

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