APPLICATION OF COMPUTATIONAL FLUID DYNAMICS TECHNIQUES FOR STUDYING WIND FORCES ON HIP ROOF BUILDINGS

[1]Rajendra PD Verma, [2]Eswara Veera Raghav Rao, [3]Dr.Shrikrishna A. Dhale
[1]Research Scholar, Sri Satya Sai University of Technology & Medical Sciences, Sehore,Madhya Pradesh
[2]Guide, Sri Satya Sai University of Technology & Medical Sciences, Sehore,Madhya Pradesh
[3]Co-Guide, Sri Satya Sai University of Technology & Medical Sciences, Sehore,Madhya Pradesh
shri22dhale@gmail.com[3]

Abstract: Most residential, commercial, and industrial structures worldwide are low-rise and susceptible to windstorms. Wind lots on low-rise structures are understudied. Unfortunately, hurricanes and tornadoes remind us of this carelessness. Post-disaster assessments show that roof failures and coverings caused most of the initial damage. Multiple building evaluations have shown increased suction pressures around roof corners, leading edges and ridges. Hip roofs, also known as hipped roofs, have all sides slope downhill to the walls, usually mildly. Thus, it lacks gables and other roof verticals. Square hip roofs are pyramidal. Hip roofs on rectangular homes feature 2 triangular and 2 trapezoidal sides. They're symmetrical centerline-wise due to their pitch or slope. They give structures a compact, attractive appearance. Hip roofs have a standard fascia, so gutters may be installed around them. Dormer-slanted hip roofs are common. This research is on using computational fluid dynamics to examine hip roof wind forces. This paper details CFD simulations of low-rise hip roof buildings. For CFD study, wind tunnel simulated data was used for inflow boundary conditions, boundary conditions, near to wall treatment, etc.

Keywords: Computational Fluid Dynamics (CFD), Aerodynamic Performance, Low-Rise Buildings, Structural Integrity, Roof Failure Analysis

Introduction

Buildings are continuously subjected to various environmental forces, among which wind loads play a significant role in determining structural integrity. Low-rise buildings, which are the predominant structures for residential, commercial, and industrial purposes, are particularly vulnerable to wind-induced damages. Extreme weather events such as hurricanes and tornadoes often highlight these vulnerabilities, causing severe structural failures. Studies have shown that roof failures, particularly in the form of uplift and displacement, are among the primary causes of damage during high-wind events. This makes understanding wind forces on low-rise buildings crucial for improving their resilience and safety. Among various roof designs, the **hip roof** stands out due to its unique aerodynamic properties. Unlike gable roofs, which have vertical sides that create wind resistance, hip roofs slope downward on all sides, reducing wind-induced pressure differences. A **square hip roof** resembles a pyramid, while rectangular hip roofs have two triangular and two trapezoidal faces. This design is known for its structural stability and aesthetic appeal, but the complex interaction between wind and hip roof surfaces remains an area that requires further study. Computational Fluid Dynamics (CFD) has emerged as a powerful tool for analyzing wind flow and its effects on buildings. Traditional wind tunnel experiments have been widely used in wind engineering, but they come with limitations such as high costs, time constraints, and difficulties in replicating real-world wind conditions. CFD provides a cost-effective and highly detailed approach to studying wind forces on buildings, allowing researchers to simulate and analyze airflow patterns, pressure distributions, and structural responses with high precision.The main objective of this study is to apply **CFD techniques to investigate wind forces on hip roof buildings**. The study aims to simulate and analyze wind behavior around hip roof structures using different CFD methodologies, with a focus on understanding pressure variations near roof corners, edges, and ridges—areas known to experience high suction pressures. By utilizing CFD, we can optimize roof designs to enhance wind resistance and reduce structural damage risks in extreme weather conditions.

Small, varied, and often incorporated into various kinds of terrain and geology, most buildings across the globe serve a variety of purposes, including commercial, residential, and public spaces. A great deal of wind. In places with high winds, such as wide fields, seaside locations, or uniform slopes, the horizontal power of the structures has to be managed. Both the wind load and the building impact assessments are necessary for a complete understanding of how wind affects structures. Modern advancements in building materials and methods have ushered in an additional age of structures and designs that are less humidified, lighter, and amazingly flexible. These structures are quite vulnerable to wind damage. Wind loads at structures downstream have not been considered due to the enormous interest in measuring such projects. It is unfortunate that we are reminded of it whenever a tropical storm, hurricane, or twist occurs. However, scientists have recently noticed the wind and conduct wind near dwellings that are low to the ground. Large populations in developing nations and emerging markets tend to congregate in lower-story structures. A low-ascent ASCE 7-05 building is one whose typical roof height is less than 20 meters. Areas prone to heavy winds and precipitation, such coastal areas and hilltops, are ideal for pitched roof building ideas. Concerns about the foundational stability of lower-story structures arose in response to the widespread use of locally sourced, less expensive, and lighter building materials in developing economies. When exposed to wind, these structures reveal their extreme fragility. Rising global temperatures and other forms of climatic change have made tropical and twisting storms more intense and more often in the last 20 years. Tornadoes, tropical storms, and cyclones wreak the most havoc on these low-rise structures. In extreme wind, the building decks are often damaged by the parallel wind force and pull. Tests conducted after twisters or tropical storms have shown that hip-type pitched towers are more wind-resistant than other roof-type constructions. Researchers have progressed into the safe construction of low-capacity buildings beneath wind turbines in response to the enormous monetary and human losses caused by wind frequencies that destroy such structures. In the past, there was a lack of testing when it came to breaking the wind over low-level structures due to the high expenditure of doing such experiments. The influence of structural measurements, such as interference, district geology, and wind speed point, makes the investigation of wind collaboration with low-lying structures perplexing. Accurate wind load insurance is crucial for reducing wind turbulence and for the economically prudent design of low-level structures, but this is no easy feat. The mathematical and structural aspects of buildings are defined by their private, commercial, or mechanical functions. The damage that wind does to a house depends on its mathematical construction, the form of its roof, and other factors. Hip roofs, in contrast to flat roofs, slant downwards around each of the four building boundaries. Hip roof buildings are characterised by roof corners and sharp edges, which may lead to abrupt changes in wind pressure and quality. The hip roofs' continual element diversity is another home impediment. Past research has looked at how shifting points, building structures, overhang lengths, wind turbines, experimental arrangements and CFD reinstallation affect the size and form of hip rooftop buildings. By examining the hip ceiling structure in relation to the hip roof construction in terms of lateral obstructions and protective effects, this research aimed to further dispel the impedance effect. Computer analysis was used to compare two hipped roof constructions with a 30° split roof dividing 0.25", 0.5" (where B is the more modest length of the building) and 1" (where B is the longer of the two). The math layout for wind turbine classes has been more and more valuable as it aided in shortening the design, testing, and improvement times of the turbines. Regardless, considerable work and progress have been made by various analysts in integrating the shopping models used to predict wake-life under various conditions, but no substantial structure has been built and no useful test estimates or results from computational fluid dynamics (CFD) have been discovered. New, more powerful computers and better CFD market programming have resulted in more precise designs and stricter regulations. To back up the mathematical concept even further, we anticipate cutting-edge measurement crossings with meteorological devices both upstream and downstream of the wind turbine. Next, the characteristics of wind turbine wakes in all-over wake zones will be statistically and provisionally examined. An investigation of the variation of wind pressure over a hipped, low-intension impedance rooftop structure and the use of computational fluid dynamics (CFDs) was suggested in this work. In the past, some roofs have taken a major beating from violent gusts of wind. The building was shown and reproduced to dispel the illusion of an obstacle in the slanted structure and to serve as a guardrail. Two similar hip roof structures that contribute 30° points have employed this test, for example with 90° wind frequency points typical of a longer construction period. Here, we mathematically reduced the building model to 1:50 and utilised wind data to rebuild the Ambiente Limit Layer (ABL) from Texas Technical University (TTU). Reynolds' Averaged Stocks (RANS) is used in computational fluid dynamics (CFD) simulations using Standard k-µ and Renormalisation bunch (RNG) k-ć shop types. The results show that the amount of wind pressure on the hip roof of the test building is affected by barriers and protection. The findings of the 30-degree-pitch single-building model's rehabilitations were authorised, in contrast to the wind tunnel detail. Results from computational fluid dynamics (CFD) choppiness models were good, and wind turbine expertise was deemed fair.

Wind Turbine Wakes

The idea of wind farms and turbines is to harness the power of the wind and transform it into usable energy, such mechanical and electrical power. Reducing the activity of the downstream energy of the wind turbine relative to the operational energy upstream of the wind turbine is a clear fundamental concept of resource protection, especially when motor energy is separated from wind energy. Consequently, the downstream wind, which is the turbine's wake, is weaker and more turbulent than it was before. Decreased power output owing to wake pace deficiencies and specifically enhanced loads on the edges owing to greater disruption speeds are presently two big concerns in the collections of turbines in ransoms. Depending on the wind turbine's design and the circumstances, the power loss and fatigue experienced by the downstream turbine may be as much as 80% more than those experienced by the upstream turbines. This wake will spread out as the wind blows downstream, and free flow conditions will be restored gradually. Wind turbine wakes have been under scrutiny from the hopeful beginning of restoring faith in wind energy consumption in the late 1970s. At first glance, wind turbine aerodynamics may seem to be quite basic and unchangeable. In both cases, the portrayal is muddled since the inflow is dependent on random wind fields and non-pitch directed machines' operational envelopes include slow-down. Actually, the wind turbine isn't the most well-known device for wasting wind power; the most famous item is the cruise ship. However, the most basic and simplified parts of the stream management system are the ones that are least understood. The bulk of investigations have shown an unmistakable split between the wake areas and the wake-up areas, with veneration for the wake regions. Only the area downstream of the wake is considered for the field behind the rotor, which may extend up to three to five widths. The impact of the rotor is more significant in this case. The nearest wake location is characterised by a distinct sharpness brought about by the edges, shear, and corruption of the tip whirlpools that travel long scale lengths. Outside of the awakening district is the far wake. The stream region in the wakes of wind turbines is incompressible because to the high velocity (5-25 m/s) experienced both upstream and downstream of these devices.

Wind Loads On Structures With Curved Roofs

The characteristically development of air corresponding to the surface of the Earth produces a quick current, much of which is 'wind' or 'air flowing.' That is influenced by the variation of temperatures in the global air and therefore compares heat, causing the air or wind to travel from the high-pressure factor area to the low-pressure locality. Furthermore, due to the harshness of the world's surface, wind waves in aggressive limits occur with the fluctuating tilt stature depending upon the scale of the earth and the length of the shore. The furious limit streams are characterized by shifting wind velocities in a haphazard manner and the existence of buildings makes the wind flow go wrong. Due to the large structures, the wind is often streaming from all sides of the house. Nevertheless, the wind is transcendent across the top of the building, owing to lowrise buildings. Because the overview of structural design innovations is at the top of low ascent structures, an investigation is needed on the effect of wind voltage on the roofs of these buildings. The roofs are usually low-ascent devices, lifting/pitching, hipping or bending. Low-ascent systems with bent roofs are being created to carry out large, unhindered passages such as amusement villages, show centers, sports fields, holders of air terminals etc. These structures are constantly constructed either on the ground or at an elevated level and have roofs that have components of low extra weight per unit of the area protected. This renders them indefensible to the wind, since they are drawn into the layer of air limit where the wind has a strong turbulence. The evaluation of wind cargoes on such roofs is therefore essential to prevent underlying deception. Figure 1. shows the mathematical limits of a bent roof at an elevated stage together with the wind points. The curved roof has an upward 'f,' 'd' range, 'h' and 'L' divisor stature. The general stature of these designs is not precisely the size and length of the building. As the ascent to the cross section extends the mark of the flux division moves in the direction of the lower side of the roof.

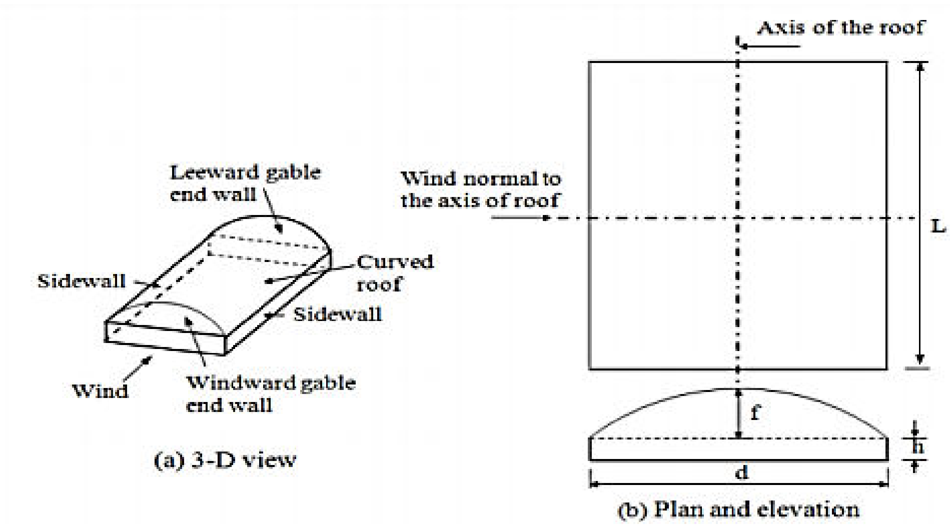

Figure 1. Schematic diagram of a curved roof at elevated level

Computational Fluid Dynamics (CFD)

Computational fluid dynamics (CFD) is the mathematical application of analytical power to the numerical interaction between a real wonder and a stream of fluid. For instance, aerodynamics is a key component of the design-build interaction when the designer is asked to construct a different object—a winning racing truck—in the next season. But it's not possible to quantify simplified cycles all the way through the ideation phase. In most cases, the architect may simplify his designs by just doing genuine trials on item templates. In response to fluid stream problems, computer fluid dynamics has grown in popularity with personal computers and their ever-increasing processing power (thanks to Moore's law!). A computational fluid dynamics (CFD) programming investigation drives the assessment of the fluid flow based on its genuine features such as speed, strain, temperature, thickness, and consistency. At all times, these characteristics should be considered in order to develop a targeted reaction to a real fluid-stream marvel. By using a statistical approach and a numerical model of the actual situation, the CFD programming tool is used to dissipate the fluid flow. One example is the visibility of Navier-Stoke (N-S) conditions in numerical models of real-world situations. This exemplifies changes in both assets caused by fluid flow and heat transfer. The nature of the issue dictates the modifications to a computer model, which might include heat transfer, mass transfer, stage transition, synthetic reaction, and so on. The whole cycle setup is the foundation of the CFD examination's unfaltering correctness. Verifying the numerical model is crucial for taking the issue seriously. Accurate statistical procedures are also necessary for a trustworthy arrangement to be realised. Since there will very certainly be fewer physical models, CFD research is essential for giving a reasonable measure of item change.

Comparison Of International Codes Wind Loads And Cfd Results For Low Rise Buildings

An important part of the construction connection is the estimation of wind loads used in the building's basic design. Nevertheless, not all types of constructed architecture are addressed by publicly available information about registered projects under these standards that are not part of the wind tunnel investigation. Consider the designer wind restrictions as experimental data that is both expensive and difficult to get your hands on. For some structures that use CFD processes, this evaluation aims to address important wind characteristics for the foundation layout, such as pressure appropriation and drag coefficient. In order to include the CFD method into these designs, we are now researching the necessary permissions for the wind tunnel results. The short gable system of a single range with mono and double slopes, brackets, and arches were among the projects that used CFD methodologies at this period. The critical boundaries considered while analysing the roof slopes and building peaks. The different pressing factor coefficients of the peak building roof areas were also evaluated in comparison to the training rules, wind standards internationally, and the CFD method. The latest wind loading regulations are based on the limit wind tunnel research' approximations of pressing factor coefficients for different building types and thermal forms. Wind burrow inspections should be put in place to safeguard this missing design aspect, which is not included in these criteria for dwelling or construction. However, most architects find the wind tunnel tests to be too general and too hard to recreate, and Reynolds's full-scale numbers pertaining to the trials are notoriously difficult to get. Using scaled models for restricted layer testing helps in statistically validating wind loads. There is no way to mimic a Reynolds number, therefore we change the boundary conditions and conduct a parametric study. After that, the gaps in the winds architectural data are filled with astonishing expectations by statistical simulation of wind difficulties, and the instructional codes are expanded for every building state. A primary goal of these experiments is to ensure that the flow area and the structures can be appropriated by means of wind pressure. The surface area of the stream, which indicates the coefficients of the pressure element, is determined via low-elevation building experiments with big wind burrows. A exhibition of cubic buildings and one cubic building of varying shapes both sought to measure wind speed and direction. The research looked at the range of strengths for various wind speeds in relation to the pressing factor changes of pitched roof buildings. For four limited-pitched roof constructions, the influence of model dimensions is examined in order to estimate the pressure dispersion at mid-building duration. Investigating the long low-level tillage tower with steep roof allowed us to analyse the effect on the outside of the wind stress distribution by duration to cross the proportions. This investigation was driven by a wind burrow test, which involved measuring the difference of wind pressure with roof pitches on the hip roof framework. Using wind tunnel testing on a single-slant, small-size model, we looked at the wind stream's visual characteristics, temperature distribution, and pressing factor appropriation, as well as two limiting angled size obstructions and one littered roof design to find the strong motor energy profiles. The research is based on a wind tunnel test that was conducted in three distinct Gable buildings with varying roof pitches, one for each pushing aspect. In the barometric boundary layer wind burrow, the circular silos with cone-formed roofs were tried. The findings specify the size-to-width distribution of wind pressure as a function of pitch angle. In an effort to provide the aerodynamic data base for the wind load assessment structure, a small-sized model of spherical domes with varying ratios and stature/length proportions was tried for two kinds of aggressive limit layers. The mathematical and preliminary computations of the wind stream expenditure over the surface of the fixed-tallness equator on two turbulent limits are meager and thick. The study includes estimates of stream area and power for both types of boundary layers. Aerodynamic wind tunnel tests on enlarged paraboloid roofs with circular plane shapes proved the goal of determining pressure coefficients. When comparing elliptic shapes to their spherical and circular counterparts, their effectiveness is often considered. Roof sheating as a result of wind loads is examined for buildings with low-rise wood outlines. There were 34 different models that were experimentally examined, and they included a wide range of characteristics, including as roof form, tower tilt, building height, upstream, and structures

It calculates the drag coefficients of 9 tiny, determined steel transmission towers by means of wind burrow tests. They equate the test findings and the CFD interpretation and the characteristics defined by some international criteria. The use of a CFD model to research the 3-dimensional stream around a rectangular cylindrical using minimal distinguishing techniques to consider the air elastic instability wonders is a good task in mathematical reproductions. The impacts of the roof form on air flow by low-lying structures is CFD. The wind caused air movement. The indoor velocity conveyance for five winds bearing investigated for level, mono slant, twofold inclines, hip and angled roofs.

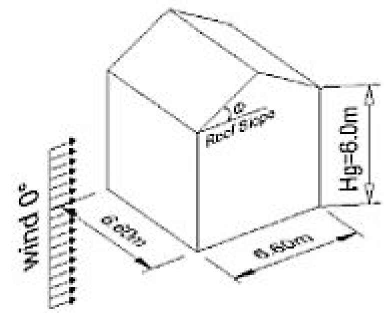

Figure 1.2: Schematic view of gable roof model

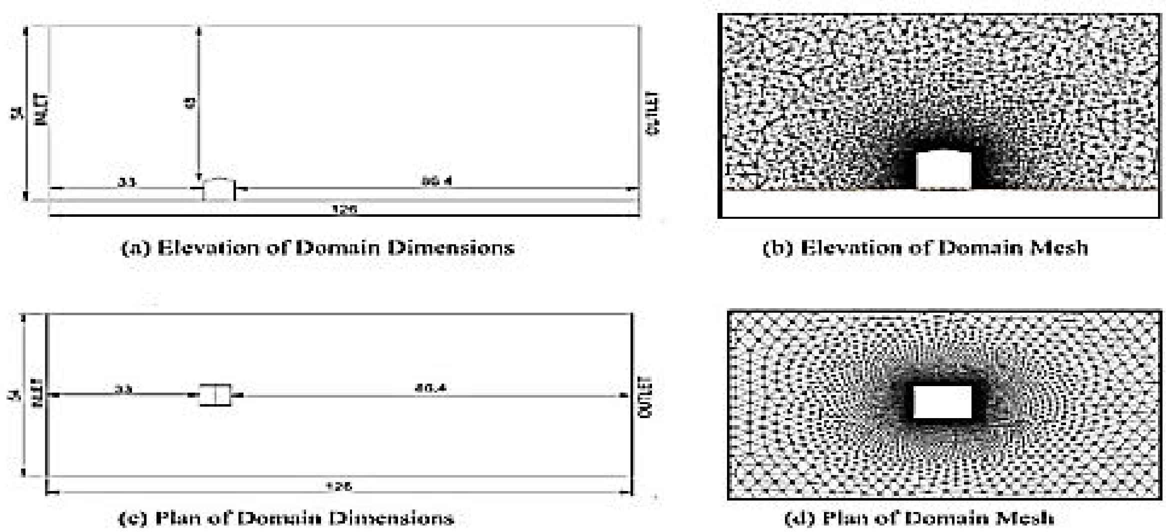

Figure 1.3: Gable roof domain dimensions and mesh

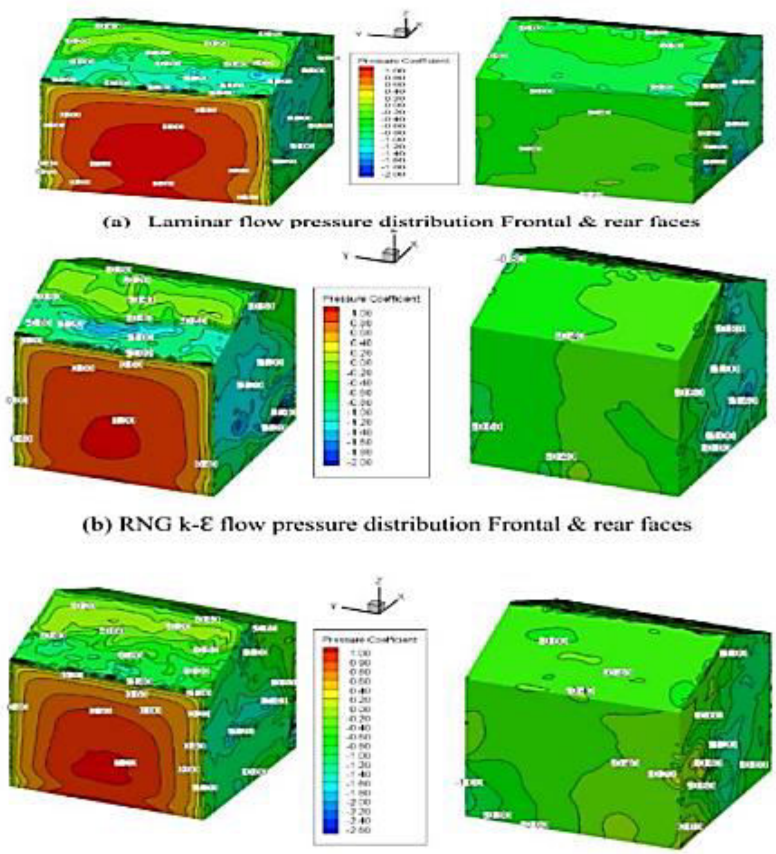

Figure 1.3: Pressure distribution for gable roof for three different flow types

Structural Interference Impact On Wind Load For Lowrise Hip-Roof Buildings

Two similar hip-roof structures were laid sideways, the difference between them being 0.25B, 0.5B, 0.75B, 1.0B (where B is the smaller roof structure = 1.4m (scaled) and 7m (model))). With this case, two buildings were laid sideway. The design/configuration of two hip compared roof buildings set lateral to investigate interference effects as seen in Figure 2.3. Figures 2.1 to 2.4 show that the wind side of each of the buildings was basically under positive pressure in the general surface near the ridge pressure, while there was a negative pressure on the side and the immense slope on the lee side. It is tended to be shown that the difference in the magnitude of the pressure coefficient is seen in the variation in the space between the two houses. If the gap between the two buildings increases, the suction stress increases at the leeward region (with two side paths and an enormous slope) and at 1.0B, the most intense suction. The highest negative pressure on the interfering building roofs as seen in Table 2.1

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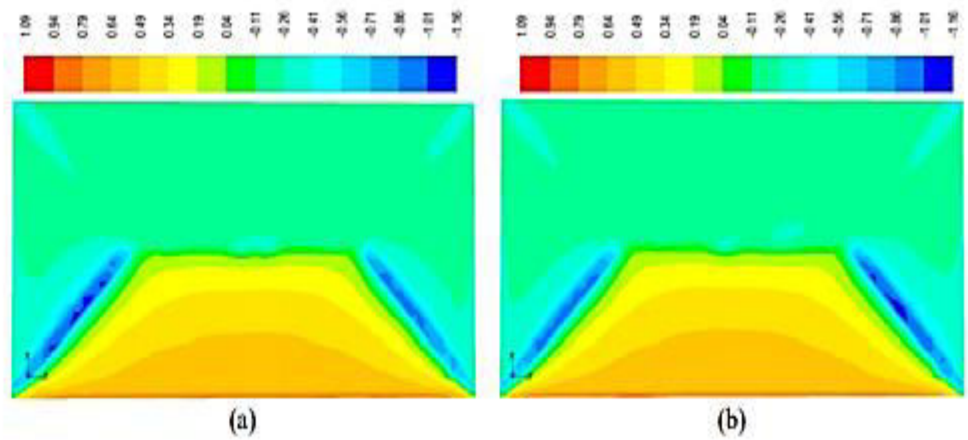

Figure 2.1 Pressure coefficient's Contour plot on buildings placed side way sat a distance of 0.25B

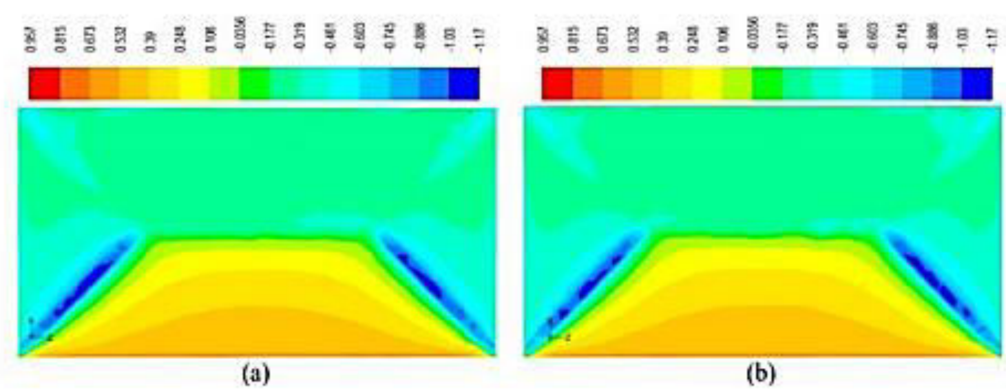

Figure 2.2 Pressure coefficient's Contour plot on buildings placed sideway sat a distance of 0.5B

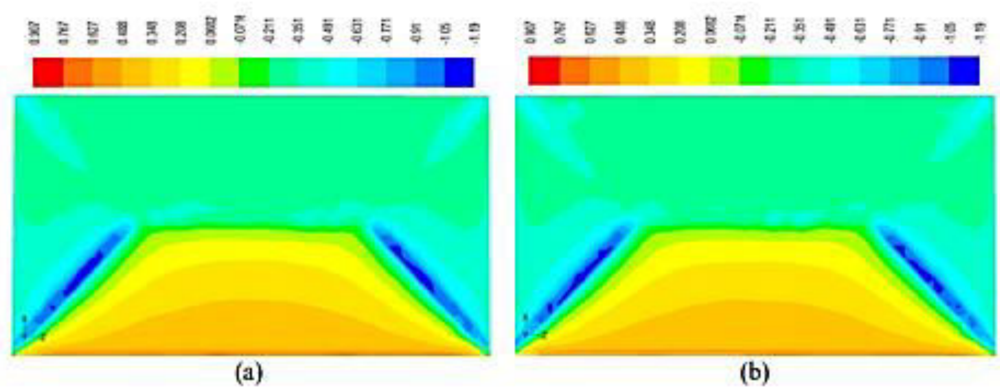

Figure 2.3 Pressure coefficient's Contour plot on buildings placed sideways at a distance of 0.75B

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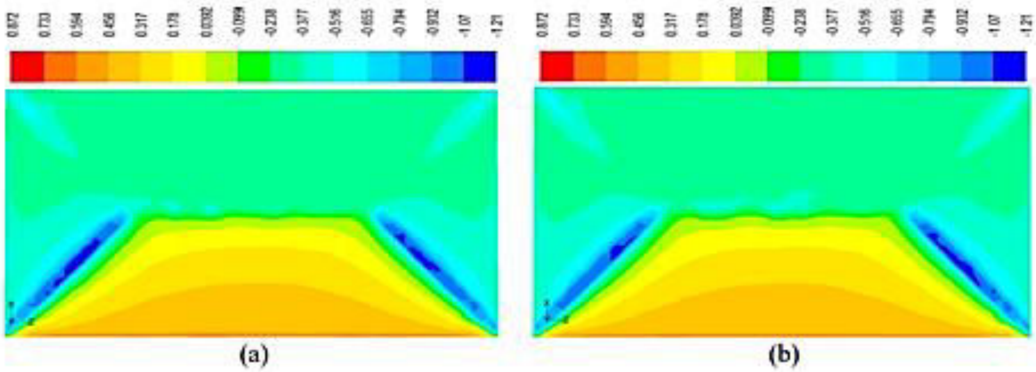

Figure 2.4 Pressure coefficient's Contour plot on buildings placed sideways at a distance of 1.0B

Table 2.1 Maximum negative value of pressure coefficient on the roof of the interfering buildings

Distance between the interfering buildings	**Maximum negative pressure coefficient on the roof**
0.25B	-1.16
0.5B	-1.17
0.75B	-1.19
1.0B	-1.21

PERFORMANCE COMPARISON OF VARIOUS CFD SIMULATION MODELS

The most notable sucking pressure coefficient at 0 ° wind incidence angle is - 0.6, and in CFD models the value is - 1.1 k-specification, - 1.2 k-strategic suction coefficients, - 0.851 k-specification techniques, - 0.946 k- techniques, - 1.02 k- SST technique occurrent on the roof rim. For the example of the press delivery, RKE, SKW and SST k- still stays virtually the same, and standard k- and RNG k- provide negative values at the slender hand. Any of the models had absolutely those areas on the windside; in any event, as we reached the ridge, the values were negative

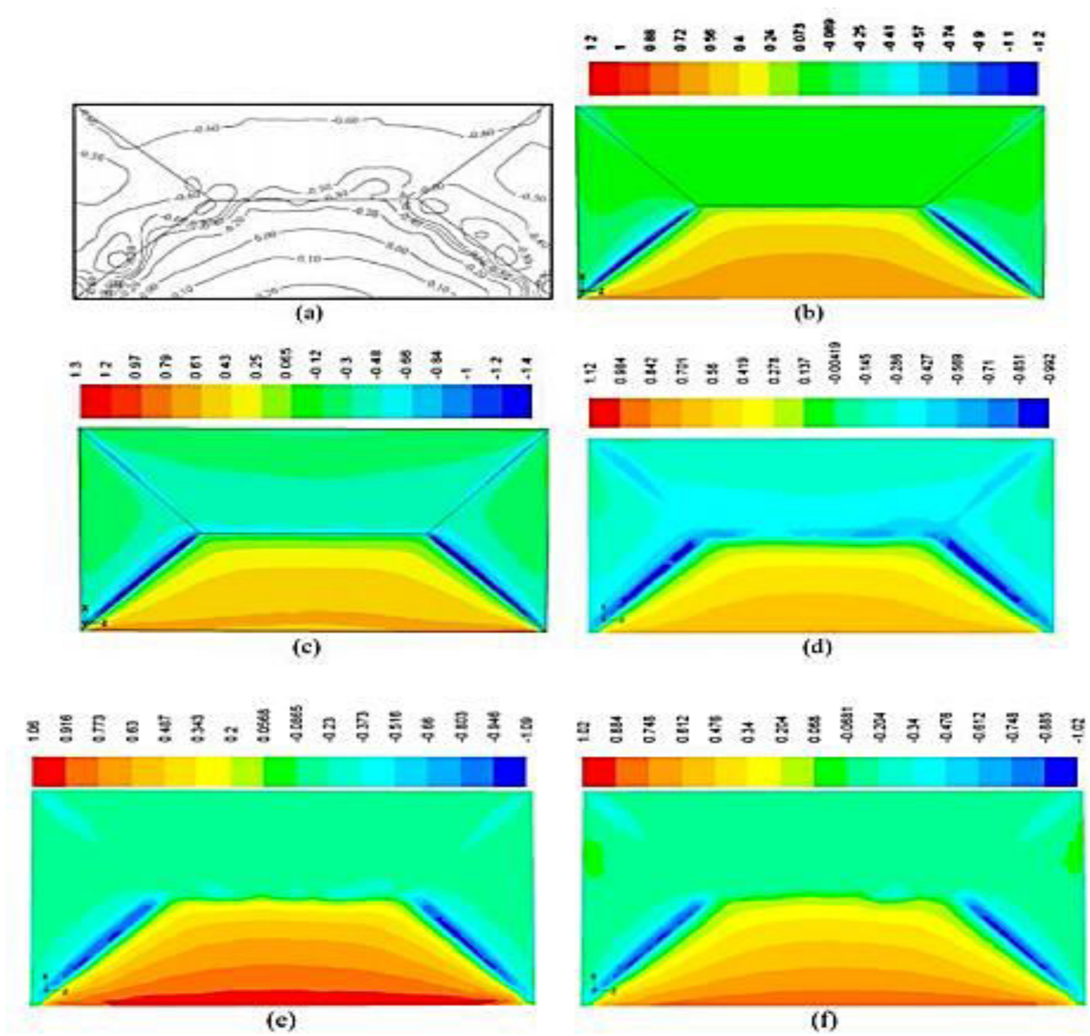

Figure 2.5 Pressure coefficient's Contour plot at 0° wind attack, on the roof by (a) Wind-tunnel (b) Standard ε–k (c) RNG ε–k (d) RKE (e) SKW & (f) SSTKW

Conclusion

This paper's goal is to provide an EIOT—an Internet of Things that is both functional and efficient—to bolster the energy management plan. Using this method, we can achieve perfect alignment and long-term resource protection without sacrificing any data transfer accomplishments. In order to make our energy storage more substantial and to identify the optimal transmission of correspondence flags in the model frame, the hypothetical and substantial correspondence shows the power consumption impact. By reducing energy consumption and maximizing efficiency in energy transmission, our EEIOT solution outperforms the status quo. An eco-friendly Internet of Things (IoT) framework, SIoT, which enhances resource utilization and prolonged item lifespan. Recreations saw a first evaluation of the system's performance in terms of hardness and energy-inclusion, which led to a halving of its solidity and a general expansion of 65%. By turning off unused devices while not in use, our design also helps keep resource consumption in check. By using energy-efficient self-planning estimate, it can put unused devices into sleep mode until a similar zone with fewer devices can be covered. Then, it can monitor the effects of traffic charge, ensuring that our device remains intense for varied traffic stacks. Discrete issues were never addressed using SOS, another strategy in heuristic areas. All of the living things in the ecosystem have been through this before, but this calculation brings new life to harmonious connection methods. The achievable performances and the customary relevance of IoT gadgets and apps with fewer resources, the measurement of thin and light arrangements across all IoT layers and applications. We compare the data from the available wind tunnel with the values of the mean wind pressure coefficients to ensure that the CFD effects are accurate. Despite appearances, substantial errors happen close to edges and steep turns, and numerical values are often beyond the realm of exploratory knowledge. This disparity exists because pressure correction on abrupt bends close to eaves is challenging in wind tunnel tests, and no further measurements of pressure coefficients in these areas have been taken. Incorporating or extrapolating the pressure coefficients has resulted in abrupt curves. All of the numbers in the most recent study add up, and most of the real-life examples show the right range and patterns.

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