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Impact of Natural Ventilation and window wall ratio for Energy Efficient Building: A Case of Residential Building at Janakpur

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Abstract

While maintaining ventilation rates that are consistent with acceptable interior air quality, natural ventilation has the potential to save construction costs and operating costs for some commercial buildings. Compared to mechanical ventilation systems, which are created specifically for the supply of fresh air, natural ventilation can achieve far higher ventilation rates. This study explores the possibility of maximizing the use of natural ventilation there by reducing the need for mechanical ventilation in the buildings, and compare the overall energy efficiency and comfort delivery by controlled natural ventilation as compared to the existing mechanical ventilation used in the case studied building. It studied the building retrofitting intervention measures that can save energy in the building having higher summer cooling loads and lower winter heating demands, a typical characteristics of southern plain terai region of Nepal. This research mainly focuses on how the window wall ratio impact on building cooling load and heating load reducing the electrical cost of the building.

Keywords

Natural Ventilation, Window Wall Ratio, Energy Efficiency, Heating Load Cooling Load

1. Introduction

HVAC (heating, ventilation, and air conditioning) systems in both residential and commercial buildings use a lot of energy to provide thermal comfort to the occupants. Despite the fact that the bulk of energy used in buildings is for heating, cooling energy demand is anticipated to increase by around 150% globally and by 300% to 600% in developing countries by 2050 due to the growth of the global economy and population [1]. Reduced HVAC energy demand will undoubtedly result in lower building energy use and, consequently, lower carbon dioxide emissions. Additionally, several other design parameters have a significant effect on heating and cooling demand in buildings, such as a building shape and orientation, wall and roof constructions, window sizes and shading, as well as characteristics of heating, ventilating and air conditioning systems.

Awareness about climate change and the urgent need to decrease carbon emissions in buildings, in combination with concerns about occupant comfort resulting from the rise of temperature, are increasing [2]. There has been an increase in interest in the creation of energy-saving systems and environmentally friendly building practices recently as a result of issues related to the reduction of energy consumption and greenhouse gas emissions. Particularly, there are a lot of studies being done on indoor environmental management using natural environmental control methods. It is largely acknowledged that almost 60% of the global energy consumption in developed countries is attributable to buildings, and that cities are responsible for up to 80% of the global CO2 emissions [3].

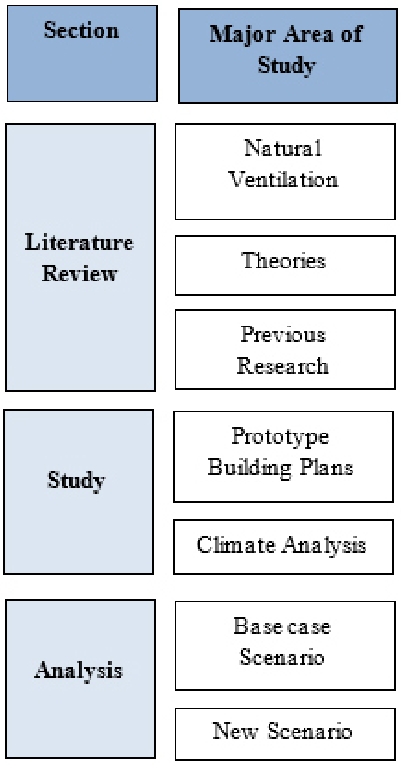
Due to these possible advantages, natural ventilation is frequently suggested as a method of energy conservation and enhancing indoor air quality in commercial buildings, especially in the ”green building” community. Without performing any engineering research to support the stated benefits, such as estimating anticipated ventilation rates or air distribution patterns, these notions are commonly advanced. Furthermore, there are no tried-and-true design techniques for including natural ventilation in commercial building systems in this nation [4].

The energy needed for mechanical ventilation of buildings could be greatly reduced with natural ventilation. Because there is little data on the thermal comfort and interior air quality of office buildings without air conditioning, it is still not commonly used. As a result, steady state ventilation air flow rates were methodically simulated for various boundary conditions, such as temperature and pressure differences between openings for various opening types, using both analytical and airflow network approaches. To calculate the annual thermal comfort and energy savings, coupled airflow network and dynamic building simulations were used.

The main objective is to identify and analysis the importance of natural ventilation for energy efficient building together with different ways to incorporate study in building design.

2. Metholdology

The methodology used in the study based on three main parts: review of literature, study of climate and project site, and finally design and analysis of natural ventilation for the considered site.



Section	Major Area of Study
Literature Review	Natural Ventilation
	Theories
	Previous Research
Study	Prototype Building Plans
	Climate Analysis
Analysis	Base case Scenario
	New Scenario

Figure 1: Methodology

The literature Study includes the study of historical development of natural ventilation, principle of natural ventilation, standards limit condition and key theories of natural ventilation. Relevant key theories that will guide the research are also studied.

Another part of research is the study of climate of Janakpur. The weather data for Janakpur is collected from Department of Hydrology and Meteorology. The collected data is used for simulation in the Ecotect with various scenario.

3. Literature Review

3.1 Background

Due to their excessive use of energy and other natural resources, buildings contribute significantly to serious environmental problems in their current state of design and use. There is a clear correlation between energy consumption in buildings and environmental harm since energy-intensive solutions sought to build a structure and supply its needs for heating, cooling, ventilation, and lighting cause catastrophic loss of vital environmental resources.

3.2 History of natural ventilation

Since the first caveman realized that ”hot air rises and cool air descends,” humans have harnessed natural ventilation to create more comfortable living environments. Everything changed when air conditioning was invented in the early 20th century. Following centuries saw the use of natural cooling in buildings. When air conditioning was created and became popular, everything changed regardless of how they were built or any open areas, buildings may retain their cooling. Meanwhile sustainability in architectural fields should encourage using minimum energy resources, using renewable materials, preserving existing buildings, and reusing energy without producing pollution [5].

3.3 Principles of natural ventilation

Before examining the potentials of combined ventilation systems, it is necessary to present and recapitulate an overview of the individual natural ventilation system as well as the primary principles that govern existing passive approaches because passive ventilation strategies are the subject of extensive research. The driving forces regulate the distribution of airflow, temperature, and pattern over a building.

3.3.1 Typical driving forces

Wind-driven force

It's normal practice to use a wind-induced device to naturally ventilate an area. The external wind causes the distribution of windward static pressure to rise, creating a positive or high-pressure area. Vortexes can develop on the leeward side, creating a low-pressure or negative zone. The pressure gradient forces the air from the positive-pressure domain into the negative-pressure region. The ventilation intensity depends on the size of the air intakes and extractors and the strength of the wind.

Buoyancy-driven force

Thermal buoyant ventilation is the term for ventilation that is influenced by temperature gradient. The inside air temperature of a building may become higher than the outside air temperature when a heating source is present. The upper portion of the area is filled with warm air, which causes an over-pressure in relation to the surroundings. Then, the air is transferred from the interior to the exterior.

Combined forces

The two natural driving forces mentioned above typically work together, though in some circumstances one driving force may be more powerful than the other. The combined forces may be mutually exclusive or balance each other out, depending on the incidence, incident wind angles, and whether the inside or exterior temperature is high. It is possible to determine the rate of airflow as a result of the combined effects using a root-square function.

3.4 The Standards of Natural Ventilation

In order to maintain the inside air's freshness and, second, to reduce the interior temperature and promote thermal comfort, the building's ventilation system introduces fresh, cool air. Based on the anticipated indoor environment, including air quality control and the goal of thermal amenity, we may set ventilation performance parameters.

3.4.1 The Air Quality Control Standard

By enhancing air quality, the air quality control standard can assist in reducing ventilation velocity. Designers should pick the minimal demand for fresh air and the frequency of ventilation correctly when it comes to ventilation design. Particularly for individuals who work in contemporary enclosed offices, indoor air quality has a direct impact on people's physical and mental health as well as their ability to perform their jobs effectively.

3.4.2 The Thermal Amenity Standard

Buildings with natural ventilation and air conditioning require different levels of thermal amenities, according to experiments. As a result, a wide variety of indoor air temperatures is achievable when using natural ventilation. The least wind speed that is appropriate at 30°C is 0.6m/s, whereas the minimum wind speed that is comfortable between 15°C and 18°C is 0.2m/s. And finally, the wind velocity increases with environmental temperature. The optimal wind speed for interior operation is less than 1.0 m/s. If the wind speed is greater than 1.5 m/s, the air flow will obstruct regular work. Mechanical solutions for HVAC requirements require significant amounts of equipment and space to sufficiently ventilate or air condition an indoor space [6].

3.5 Window – to – Wall (WWR)

Windows can significantly affect a building's performance. The window-to-wall ratio (WWR) is the proportion of an exterior wall that is made up of windows. Windows give buildings their aesthetic appeal, allow in light, provide views, and act as a thermal barrier. WWR represents the proportion of exterior wall surface area that is glazed and WWR affects many building attributes: window size establishes the physical/visual connection to the exterior, and determines the environmental impacts associated with material use [7]. The window-wall ratio is one of the most important energy-saving design elements that has an impact on a building's energy consumption (WWR). In order for a building to be energy efficient, WWR must be analyzed and optimized. Since the building's WWR and total energy consumption are closely tied, lowering the WWR lowers overall energy consumption.

3.6 The Limit Condition in the System Design of Natural Ventilation

Many obstacles have impeded the implementation of natural ventilation technology as a cost effective solution. Still there are various limit condition in design of natural ventilation which are described below:

3.6.1 The limit of heat gain

Difference in indoor and outdoor temperature have better impact of natural ventilation. Low-temperature outdoor air can be breathed in through indoor air ventilation, bringing the inside temperature down. The ventilation system's cooling effect increases with the size of the interior temperature difference. Using the natural ventilation system can efficiently lower the air-conditioning operation load in a typical building that depends on the air-conditioning system for cooling.

3.6.2 The requirements of building environment

The outside environment can have a disastrous impact on interior air quality and noise control in addition to the temperature and humidity of the air. Current regulations state that the noise level shouldn't be more than 70 decibels when it comes to a structure that utilises natural ventilation. When the windows are open, the noise level outside shouldn't be louder than 55 dB. The outdoor air used in the natural ventilation air inlet must also meet the necessary hygienic standards.

3.6.3 The Limit of Building's Conditions

In terms of building orientations, air inlets in the system should face the primary wind direction to make the most of wind pressure. Building orientations are also utilised in the associated process of heat reduction strategies. First, the air inlet side of the system should consider the regulation of natural lighting and sunshine heat when deciding window size, the ratio of the outside wall to windows, and the ratio of the external wall to windows. Indoor thermal load is used to produce compressed thermal pressure and increase natural ventilation in buildings with tall story heights. Natural ventilation has a big impact on lowering the temperature in a room. However, it has minimal effect on altering or managing the humidity level in the home. As a result, in humid environments, natural ventilation should be avoided.

4. Research Setting

Janakpur is a sub-metropolitan city in Dhanusha District, Madhesh Province, Nepal. The city is a major destination for spiritual and cultural travel. The city was established in the start of the 18th century. Tradition has it that the location once had a city called Janakpurdham, which served as the alleged capital of the Videha dynasty, who once governed the Mithila region. Janakpur is located about 225 km (140 mi) southeast of Kathmandu. As of 2015, the city had a population of 173,924. The city had a population of 195,438 in 2021.

Janakpur is located in the Terai, where the climate is humid subtropical: the months of March and April are hot, dry, and windy. The wet season lasts from May to September, followed by mild dry autumn from October to November. It is a cold winter from December to February.

5. Simulation

The chosen structure for the Ecotect simulation is two storey modern residential building located at Janakpur (Ward 1). East facing building of ground coverage 988.24 sq.ft consist of bedroom – kitchen/ dining - Toilet on each floor. Staircase is positioned on South direction as the buffer zone to reduce the impact of solar radiation on building while living, bedroom , kitchen and toilet on other side. All room are well ventilated but not the cross ventilation system. Along with the large window in all room fan is also used for the cooling purpose.

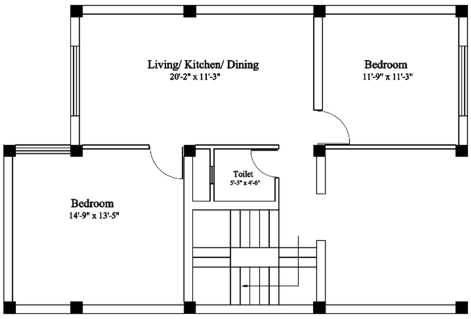


Figure: Ground Floor Plan (988.24 Sq .ft)

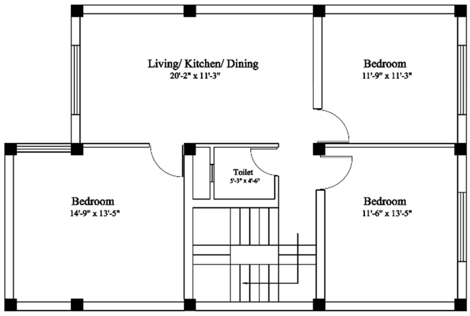


Figure: First Floor Plan (988.24 Sq .ft)

Figure 2: Floor Plans

5.1 Base Case Scenario 30% WWR

5.1.1 Material Settings

Wall Material: The external and internal walls were made up of brick with cement plaster on both. The walls were made up of 110mm brick with 10mm cement plaster on both sides and had the U-value of 2.620 W/m2K.

Floor and Ceiling: The floor on ground floor is made up of concrete slab on carpet on top and ceiling were made up of concrete slab of 100mm thickness with 10mm plaster on both sides.

Window and Door: Single glazed timber frame was used in all face of building. 6mm thick glass with density of 2300kg/m³ and specific heat of 836.800 j/kg.k was used. Also its U-value is 5.1w/m²k and Solar heat gain coefficient is 0.9. For door solid core pine timber is used.

5.1.2 Zone Setting

Zone setting regarding internal design condition, occupancy/ operation, thermal properties are set according to the site condition. The case study building model was then simulated to analyze its thermal in its existing conditions. The parameters used for the simulation are given below:

Internal Design Condition

Clothing: Shorts and T-shirt (0.4 clo)
Air Speed: 1.0m/s

Occupancy/Operation

No. of People: 2 – 3 person/room
Activities: Reading, Sleeping, cooking, resting
Air Change Rate: Average (1ach)
Thermal Properties
Active System: Mixed Mode System

Thermal Properties

Active System: Mixed Mode System

5.2 Other Cases

Different scenario were checked to evaluate by changing the WWR keeping all the properties as same as in base case. The other cases was created with 35%, 25% and 20% WWR.

6. Result and Discussion

6.1 Base Cases

Monthly Heating/Cooling Load

The total annual heating load by prototype building is 4450.079 kWh. The analysis shows maximum heating load is 7.567 kW at 6:00 on 16th January. The total annual cooling load is 8102.279 kWh. The building has maximum cooling load of 9.694 kW at 16:00 on 9th May. Therefore, the total annual heating-cooling load of the building is 12552.358 kWh. The heating and cooling load per meter square of the building is 24.694 kWh per m² and 44.960 kWh per m² respectively.

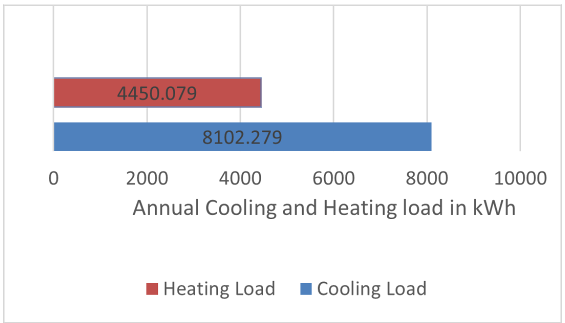


Figure 3: Total Annual Cooling and Heating Load for Base Case

Passive Gain Breakdown

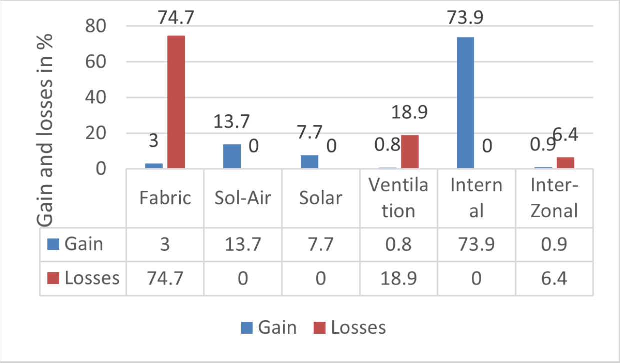


Figure 4: Passive Gain Breakdown

Analysis result shows that the annual losses through fabric is 67.5% and gain is 3.0%. Sol-air gain and solar gain is 13.6% and 7.6% respectively. Likewise, ventilation losses is 26.6% and ventilation gain is 1.2%. The total internal gain of the building is 73.6%. Building has inter-zonal loss of 5.9% and gain is 1.0%.

6.2 Other Scenario Result

The heating and cooling load in base case (30% WWR) is first calculated. It is seen that thermal load increases with increase in WWR and decreases with decrease in WWR. The building with different WWR is analysed from 35% to 20%. The annual cooling load and heating load in 30% WWR is 8102.279 kWh and 4450.079 kWh respectively. While the annual cooling load and heating load in 20% WWR is 7536.973 kWh and 4018.074 kWh respectively.

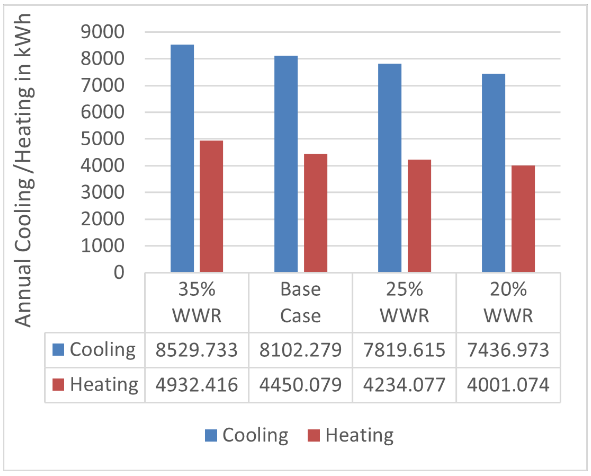


Figure 5: Annual Heating and Cooling Load

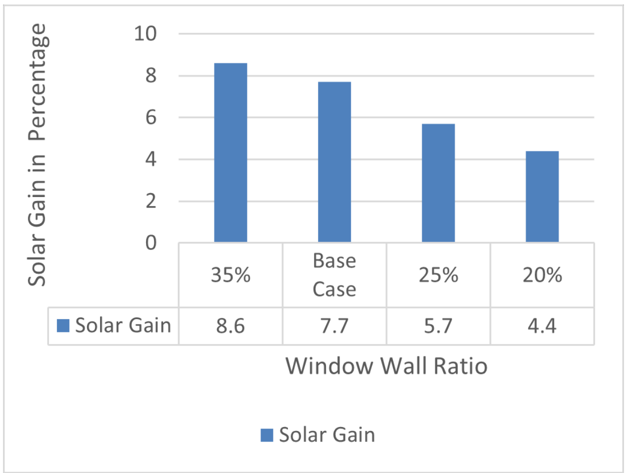


Figure 6: Solar Gain in 35% base case, 25%, and 20% WWR

Through the analysis Passive gain breakdown of building with different WWR, loss and gain aspect of the various component of the building like fabric, sol-air, solar, ventilation, internal, inter-zonal was analysed. With increase in WWR solar gain increased while ventilation loss decreases with increase in WWR.

Also the Cooling load per area in base case, 25% WWR and 20% WWR is 46.807 kWh per m², 45.113 kWh per m² and 44.043 kWh per m² respectively.

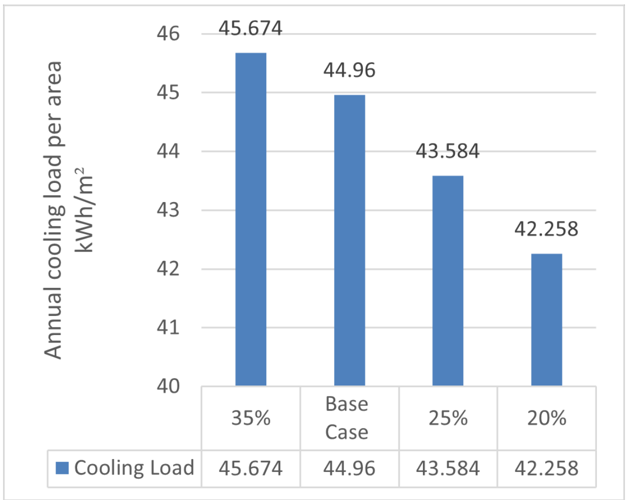


Figure 7: Annual Cooling Load per Area

The maximum cooling load at particular point in a year in base scenario is 9.6 kW which drop down to 8.1 kW in 25% WWR and 7.21 kWh in 20% WWR.

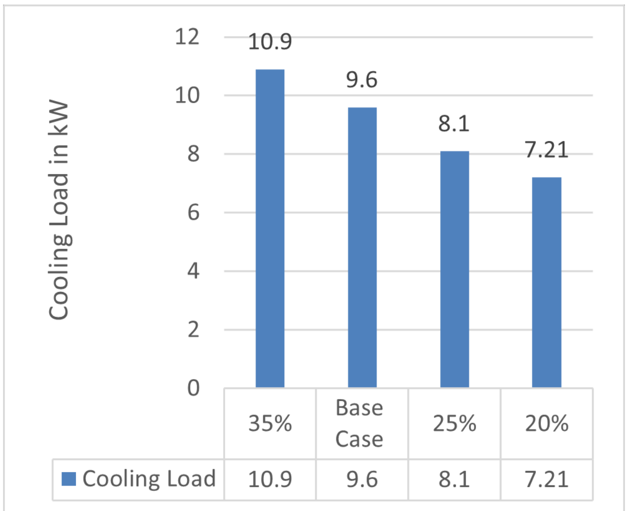


Figure 8: Max Cooling Load in 35%, Base Case, 25% WWR and 20% WWR

Similarly, the annual heating load seems to decrease from base case to building with 20% WWR.

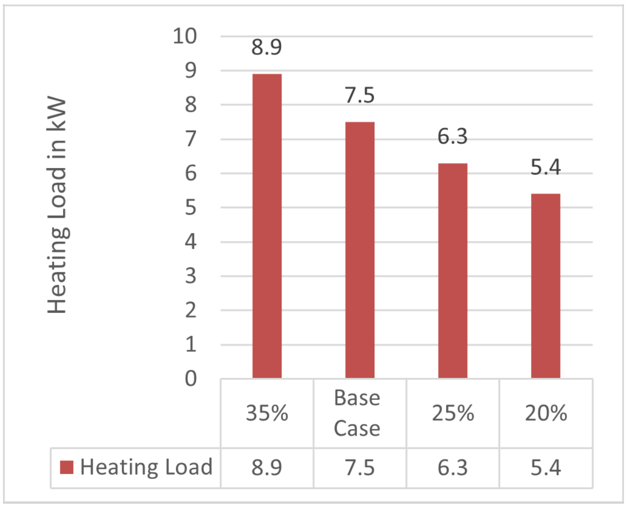


Figure 9: Max Heating Load in Base Case, 25% WWR and 20%WWR

7. Conclusion and Recommendation

After the simulation of various scenarios result shows that the building with lower WWR gives better performance in terms of both cooling load and heating load. The annual cooling load and heating load in building with 20% WWR with respect to base case is decreases by 8.2% and 10% respectively. Solar gain seems to decrease with lower WWR whereas Ventilation loss increases with lower WWR.

Overall analysis is performed with regard to WWR, and it shows how the value of the thermal load varied as WWR changed. WWR reduced the energy load but was not the cause of the building's overall energy load decreasing. Building orientation is essential for reducing the thermal load inside the building along with the WWR. The study also showed that, in addition to WWR, the orientation of the windows plays a considerable influence in energy usage. So, different orientation with WWR in a building result in energy efficient which should also be carefully taken into consideration while designing window to wall ratio in the building.

Due to the time limitation for us to complete this study, the project is focus on specific area. Most of the data are secondary type which are collected from various source. This paper may not cover every aspect of climatic impact on built space.

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