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Integrating Energy-Saving Strategies with Biophilic Design Concepts to Increase Thermal Comfort

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Abstract

Collectively, both building construction sectors account for almost 40% of all direct indirect CO2 emissions over one-third of all final energy consumption worldwide. Humans must accept responsibility for its impact on the environment create a thorough energy-saving strategy. As a result, it's crucial that we switch to renewable energy sources focus on energy optimization, efficiency, cost reduction. With the introduction of contemporary housing in the nation, that is aesthetically pleasing economically practical but typically lacks energy-saving features, particularly for thermal comfort, which drives up the cost also increases energy consumption. Individuals have lost their connection to nature due to modern living. Using biophilic design, which has the potential to maximize the advantages of environmentally friendly buildings in terms of energy efficiency practical improvements to inhabitants' comfort, health, wellbeing, is a key component of this study. Two homes at Green Hill City, Lalitpur were simulated using Ecotect & SketchUp in this study as a test case for the utilization of biophilic design energy-saving strategies. Examining daylighting, thermal comfort, energy use in the case area were the study's main objectives. The study's conclusion presents a quantitative examination of the enhanced building performance while also assessing the suggested biophilic strategies. Out of the two situations, Scenario 3 displays the fewest discomfort hours, 40% to 36%, indicating that the ratio of comfort hours to comfort hours is 59% to 64%.

Keywords

Biophilic design strategies, Energy efficient strategies, Altering building envelope, Simulation, Case studies

1. Introduction

The natural ecosystem is progressively deteriorating & the limited natural resources are on verge of depletion. In addition to this, rapid population increase & expansion of resource-consumption, combined with industrialization, urbanization & resource intensive lifestyle are contributing to worldwide environment, social & economic crisis. A human tendency to feel a connection to nature, raises pro-environmental behaviors & helps people conserve energy in constructed environments [1]. Present construction techniques ignore the benefits that incorporating nature into a building design may have on people's well-being health. Biophilic design can be seen as the key to addressing the issues of climate change environmental protection. It has a high potential to make a significant contribution that will not only magnify the benefits of sustainable buildings from an energy-saving strategy but will also practically improve users' enjoyment, health, well-being.

The majority studies have shown that using BD in a sustainable built environment can improve human performance[2]. these strategies have not been thoroughly studied in terms of maximizing energy performance. The purpose of this study is to provide a BD strategy to reduce this gap provide design strategy based on utilizing natural components & processes that increase BD energy efficiency. Two individual homes at Green Hill City, Lalitpur were provided with suggested approach. The house was redesigned incorporating BD elements in Sketchup to boost performance, & computational simulations with Ecotect were run to compare before & after scenarios.

2. Objective of Study

Understanding the implications of bringing nature into architectural design is the main objective in order to ensure human comfort while also enhancing energy efficiency.

Additionally, secondary objectives include examining the shift in building materials for building envelopes to ascertain how many hours of discomfort might be reduced by incorporating biophilic energy-efficient solutions to give homeowners the chance to make improvements in terms of energy use & re-connecting with nature.

3. Method of study

Figure 1: Framework for research

Figure 1 displays the research's methodology. The research process began with the definition of the research's objective before going on to a literature review. Both qualitative quantitative research are used in this study. The literature review was done using research papers, journals, online sources. Case studies from a variety of related research, information from the internet, climatic data, technical details on suggested materials, on-site inquiry form Nepal & Norway, climatic data were gathered from the Department of Hydrology & Meteorology, from 2010-2020 were used to gather the necessary data after the literature review was created. Additionally, climate consultant software was used to perform a comparison analysis energy modelling on the data.

Additionally, ENERGY MODELLING utilizing ECOTECT, which integrates a comprehensive 3D simulation with the vast range of analytical tools required to fully helps underthrow a building design performs, that is a highly visual & interactive analysis tool. That is used in this study to demonstrate through a computerized, visual simulation how many hours of discomfort can be reduced by changing the building envelope. However, SketchUp was also used due to software's restrictions on introducing BD approaches. Data analysis was followed by the section on interpretation & conclusion.

3.1 Research Paradigm

Since the research involves both a quantitative a qualitative approach to methodology, the pragmatic research paradigm was employed for this study.

3.2 Ontological claim

The ontological claim for the study is that, the development of biophilic architecture will be beneficial as it will be step towards sustainable environmentally conscious design for housing sector for Kathmandu Valley that not only considers filling the gap of human disconnection with nature but also implement strategies that will lessen energy consumption.

3.3 Epistemological consideration

The epistemological consideration in the research is guided by the past researches done in biophilic architecture energy efficiency.

4. Literature Review

Current energy-related building performance improvement initiatives rely mainly on technology solutions, which frequently result in design outputs that lack the human component miss the need of reconnecting humans to nature [3]. Improving a building's energy performance involves reducing its energy use. The contemporary living standards, which, together with urbanization, have severely diminished people' possibilities for interaction with nature [4] . The built environment contributes significantly to this distance but it may also provide a chance to reestablish this missing link; biophilic design (BD) is being more recognized as an approach that can help reconnect human nature [5].

4.1 Biophilic design

Biophilic Design emphasizes the value of open space, natural light, natural materials, textures & plants. It is the concept of reconnecting humans with nature by incorporating light, vegetation, water, & other natural components. it is an architectural concept that seeks to bring building occupants connected to nature. Natural lighting & ventilation, natural landscape features, & other components are often used in biophilic designed buildings to provide a more productive & pleasant constructed environment for humans [5].

Six fundamental biophilic design concepts

- Environmental characteristics - Using natural world features in your constructed surroundings. Color (e.g., earth tones), water features, sunshine, genuine plants can all be used into your design.

- Natural forms shapes - Representing using natural shapes such as floral motifs, columns, ovals, arches, shells spirals, animal motifs, biomimicry (the imitation of living things). Straight lines right angles are the polar opposites of this & are rarely observed in nature.

- Natural processes patterns - Including natural qualities (rather than representations) in your design. This complicated, subtle approach is concerned with altering the sensory experience through transitions & complementing contrasts with things.

- Light space - Life cannot exist without light. This concept is focused by how light is used in a place, including natural light, diffused light, shadow, openness, architectural balance, & inside/outside spaces.

- Place-based connections - The integration of culture environment has its beginnings in the urge for humans to claim territory. This approach takes into account features of particular ties to location, native materials, landscape orientation ecology, as well as staying away from the monotony of ”placelessness.

- “Hanging interactions between humans nature - This idea focuses on how people environment are inextricably linked. These environmental values encompass elements that promote spirituality, aesthetic wonder terror of nature, self-esteem, aesthetic appeal to the natural world.

4.2 Energy efficient Design Strategies

[6] states that, the foundation of energy efficiency in buildings is linked to the energy supply necessary to achieve the intended environmental goals with the least amount of energy use conservation”. Study claims that, “HVAC systems, & artificial lighting account for the majority of this energy dem & by reducing this dem &, considerable savings in energy consumption may be realized”.

[7] verifies “33% less energy can be consumed by using design techniques such greater thermal insulation, shading, thermal massing, optimal window-to-wall ratio (WWR) skylight size”. The building envelope as the distinction between a building’s inside & outside making climate management easier & safeguards the indoor environment”. The aesthetic thermal comfort of building occupants, as well as energy usage, are significantly influenced by the design aspects of an envelope. Climate is one of the most significant variables that determine envelope design in commercial buildings, insulators, also known as thermal insulation materials, are utilized to reduce the energy consumption of cooling & heating systems. Different Types of Insulation systems are extruded polystyrene board, rock wool, glass wool, spray polyurethane foam etc.

4.3 Incorporating biophilic elements in energy-saving techniques

Among the many energy-efficient design solutions available, for this research those that reduce the HVAC load while keeping optimal energy consumption are taken into consideration. Among the strategies are- WWR, optimal skylight utilization, thermal massing, insulation are taken into consideration. How the design of a building can be affected by natural air to improve both occupant health overall energy consumption, more. The energy-saving techniques utilized in the Norwegian case study homes were also incorporated into simulation software.

5. Case Study Area

5.1 Introduction

Located in the temperate zone between 27°36’ 27°50’ north 85°7’ to 85°37’ east longitude, Kathmandu valley is a large flat valley with an elevation of roughly 1400 meters above sea level. The weather is warm enough to be comfortable, with neither a harsh winter nor intense tropical heat rain. Autumn, winter, spring, summer are the four distinct seasons of Kathmandu’s temperate environment. Lalitpur is located on an elevated area of the Kathmandu Valley, south of the Bagmati River, which divides it from Kathmandu on the northern & western sides. On the eastern side, the Karmanasa Khola serves as the border. It was created on very thin clay & gravel deposits in the center of the Nagdaha, an ancient lake that had dried up.

5.2 Data from Site Visit

The two homes of Mrs. Shrestha & Mrs. Adhikari in Green Hill City, Lalitpur, were the subject of a field visit at Nepal. Following a thorough discussion with the relevant stakeholders, a site inspection was performed. According to an on-site interview, both households experienced thermal discomfort, particularly during the winter months.

This was supported by the power bills that were acquired, which showed that electricity was mostly used for heating during this time.

5.3 Lalitpur Climatic Data

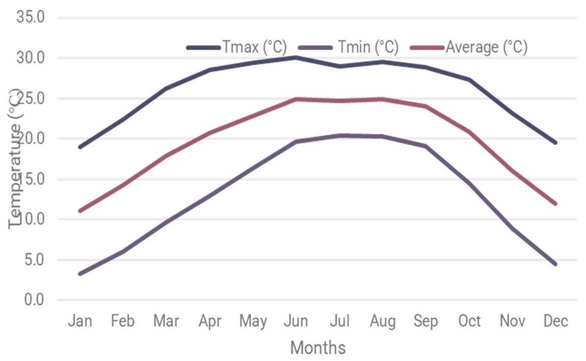


Figure 2: Average temperatures from 2010 through 2020 (From Department of Hydrology & Meteorology)

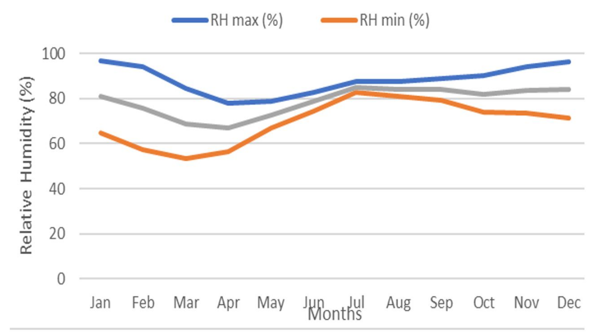


Figure 3: Average temperatures from 2010 through 2020 (From Department of Hydrology & Meteorology)

The climate details of Lalitpur collected from the Department of Hydrology & Meteorology are shown below. Data from 2010 to 2020, including dry bulb temperature, relative humidity, & rainfall was gathered from the Department of Hydrology & Meteorology. Figure 2 following shows the average temperature & relative humidity data. The analysis of climatic data from DHM shows that, the warmest month is June with maximum temperature of 29degree C & the coldest temperature is during January with minimum temperature of 3-degree.The average monthly maximum Humidity is 88.30% & average monthly minimum humidity 77.72%.

Case Studies from Nepal & Norway

Green Hill City –Nepal

This project stands out from the competition because to a thoughtful combination of design & construction that is both affordable & environmentally sustainable. It is located 2.2 kilometers from Gwarko Chowk, the construction of 95 homes on 5.66 acre of land began in June 2016 & was finished in June 2020. The site's entire size is 5.66 acre or 22893.17 square feet. 15% of the total site were utilized for open areas, gardens, & roadways. It is an independent housing project. Modern homes range in size from 1900 square feet to 3000 square feet. Five distinct types of two & a half storey structures.

Figure 4: Houses at GHC, Lalitpur Source: author

Nidelven Terrace Housing, Norway

This project's adaptation to the site & the environment has also been greatly aided by the sustainability & biophilic philosophies on which it is based. The buildings are situated to provide views of biophilic features, particularly the Nidarosdomen church & the Nidelva river. The residential blocks have simple, compact designs to avoid thermal bridging. Despite flat floor plans, galleries, oriels, & balconies have been a part of the planned architectural style & aesthetic instruments to create diversity as well as simple access to biophilic components at its immediate surrounds.

Figure 5: Nidelven Terrace Housing, Norway Source: author

Mr Larsne's Residence, Norway

This house was carefully examined to learn more about the construction materials used in Norwegian homes, particularly for the building envelopes of the walls, windows, doors, roof, & flooring. The housing uses polystyrene foam insulation around all openings & features simple, compact designs to prevent thermal bridging.

Figure 6: Mr. Larsen's Residence Source: Author

Lovashagen housing, Norway

It was constructed using a straightforward & practical approach to energy efficiency in housing. The sustainability philosophy on which this project is built has also been a major factor in the adaptation to the site & the surrounding environment.

Figure 7: Lovashagen Housing Premises Source: Solvar

6. Result & Analysis

6.1 Base Case Model/ Inputs

Materials for construction of Type A & Type B

It is constructed of contemporary elements including steel, aluminum, cement, wood, & brick. The building is an RCC-framed construction with 300mm by 300mm-wide columns. The interior partition walls are constructed with 110mm brickwork with plaster on both sides, while the outside wall of the structure is formed of 230mm brickwork with plaster on the inner side. The windows are single-glazed, aluminum-framed, transparent, 6mm thick windows. For simulation type A. Mr. Adhikari's house & type B. Mrs. Shrestha's house has been chosen.

Figure 8: Mr. Adhikari & Mrs. Shrestha's residence Source: Author

The following input parameters are taken into account by ECOTECT Energy Modeling for both the base case & test scenarios:

- Clothing = 1.00
- Relative Humidity (%) = 60
- Air Speed (m/s) = 0.5

- Lighting Level (Lux) = 300
- No. of People = 3
- Activity = Resting (45 KW)
- Wind Sensitivity (ACH) = 0.5
- Efficiency (
- Type of system = Natural Ventilation
- Upper thermal comfort level (°C) = 26
- Lower thermal comfort level (°C) = 18

6.2 Test Scenarios

Different test scenarios were taken into consideration for both houses in relation to the climate in Kathmandu valley with a primary focus on modification of the existing building envelope & incorporating BD. Here is a list of scenarios created that were taken into consideration: i. Scenario 1 – CSEB walls with low-e double glazed aluminum framed openings ii. Cavity Wall (50 mm Cavity) with low-e double glazed aluminum framed openings & 19mm polystyrene foam board insulation around the openings.

6.3 Proposed Scenarios Analysis/ Comparison

The base model first needs to be inspected to ensure that it appropriately represents the overall building performance before the variation between energy consumption before & after the many proposed scenarios can be evaluated. It has been used to run energy consumption simulations that account for daylight factor, thermal comfort, & energy usage. It is the user interface for the Ecotect simulation engine, & it is used to create a 3D model of the selected case study. The structural elements of the building envelope were chosen based on the case location in Nepal, & alterations to the building envelope were then made utilizing materials from the case study locations in Norway. However, it is confirmed that they are accessible in Nepal & in the software before using the building materials from the Norwegian case locations in the simulation. Following analysis, various material & energy-related modifications to the building are made in an effort to improve its energy efficiency. The analysis outcomes of the various scenarios are then compared.

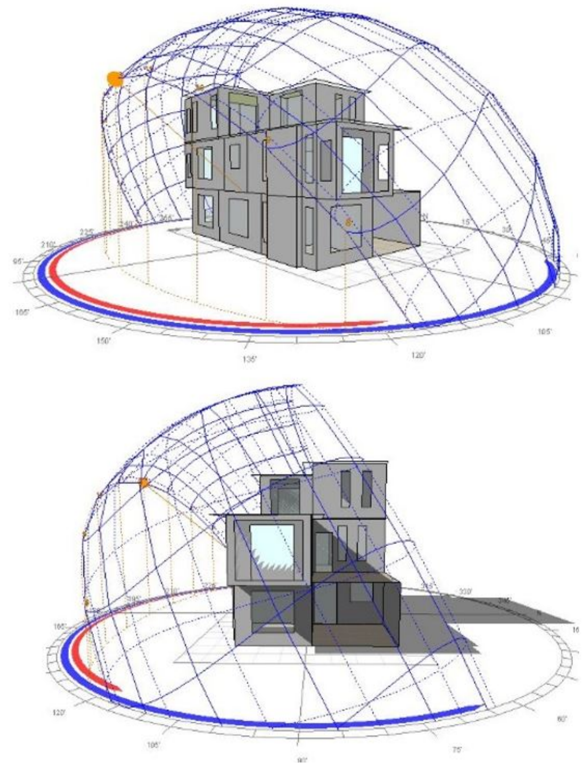


Figure 9: Type A &Type B house Ecotect model

Simulation result of Base Case Scenario- Type A &B

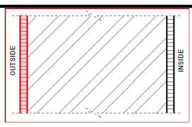
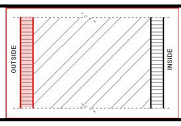
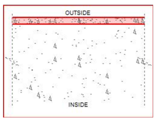
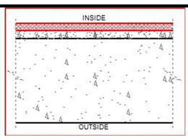
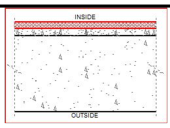
The base case was modelled as an actual case. All requirements were based on measurements & circumstances taken from the real location. The best technique to simulate the real site results was used to mimic this scenario.

Monthly loads / discomfort of all visible thermal zones, Living Room &Bedroom for base case

Calculations by Ecotect Analysis resulted in the graph below, which displays the annual percentage of discomfort period. The graph demonstrates that, with natural ventilation, comfort levels are exceeded as a result of heat loss during the course of the year & at various time intervals, with June showing the highest temperatures. The low thermal environment, however, is primarily felt from November to March. The findings indicate that the highest & lowest heating & cooling loads occur in January & June, respectively. The graph below demonstrates that the percentage of cold months is larger, increasing the likelihood that energy will be used to heat a home annually.

Percentage of time that is too hot 25.6% & percentage of time that is too cold is 92.8%.

Table 1: Building Components at base case & U-Value calculation

	Cross Section	Calculated U-Value
External wall: 230mm brick wall with 12mm cement mortar plaster		1.606 W/m2 ˚C
Internal wall: 110 mm brick wall with 12mm cement mortar plaster		2.803 W/m2 ˚C
RCC Slab		0.54 W/m2 ˚C
Flooring- Tile Flooring for Kitchen and Bathroom		0.88 W/m2 ˚C
Flooring- Timber Flooring for All rooms		0.76 W/m2 ˚C

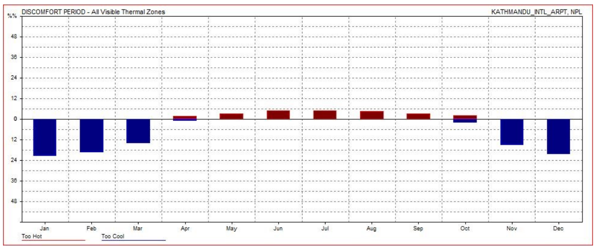


Figure 10: Discomfort degree hours under natural ventilation

Percentage of time that is too hot 0.3% & percentage of time that is too cold is 109.2%

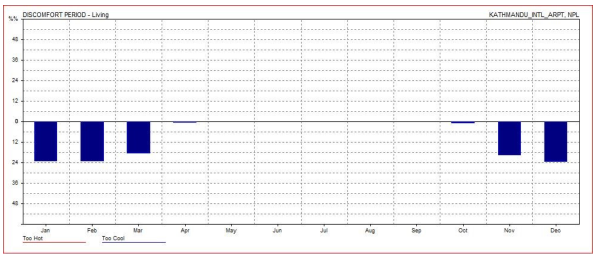


Figure 11: Monthly load /discomfort in living room

Percentage of time that is too hot 0% & percentage of time that is too cold is 287.9%. This graph proves that, Cold months% is higher i.e., leading to higher chance of application of energy for heating the home.

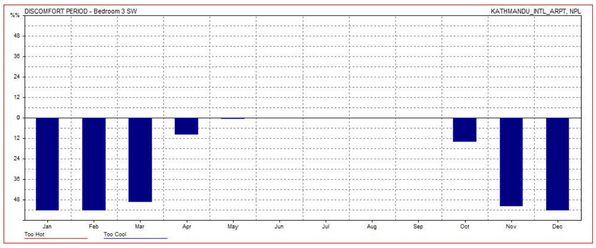


Figure 12: Monthly load /discomfort in Top floor Bedroom

According to the graph, conduction loses heat at a rate of 62.1%, which is higher than that of other processes like ventilation, which loses heat at a rate of 20.8%. Similar to this, direct gain provides the most to heat gain, at 45%, & internal zonal gain, at 22%.

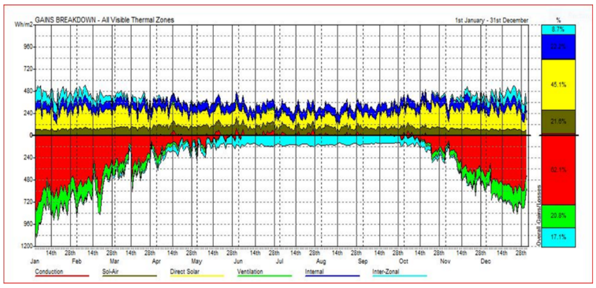


Figure 13: Monthly load /discomfort in Top floor Bedroom

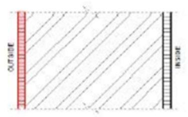
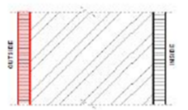
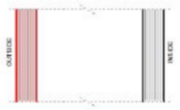
Proposed Scenarios Analysis:

For Housing type A- Compressed Stabilized Earth Bricks in Scenario 2 (CSEB)
In case 2, the outer wall is made of 240mm CSEB, while the inside wall is made of 125mm CSEB. Windows with an aluminum frame & double glazing are utilized.

Percentage of time that is too hot 28.6% & percentage of time that is too cold is 91%.

Figure 14: Passive breakdown under natural ventilation system

Table 2: Building Components at Scenario-2 & U-Value calculation

Building Component	Cross section Detail	U-value (w/m²-k)
External wall: 240mm CSEB with 16mm plaster on exterior and interior.		1.41
Interior wall: 125mm interior wall with both sides plaster		1.78
Window : double glazed Low-e Aluminium		1.6

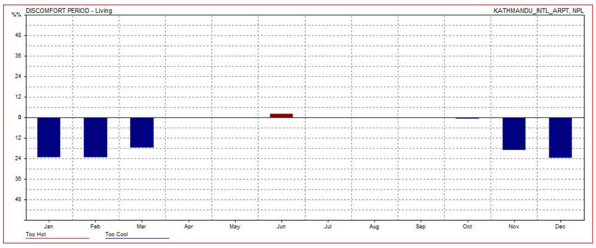


Figure 15: Monthly discomfort in Living room

Percentage of time that is too hot 2.8% & percentage of time that is too cold 105%

Percentage of time that is too hot 0% & percentage of time that is too cold is 208%. This graph proves that, Cold months % is higher i.e., leading to higher chance of application of energy for heating the home.

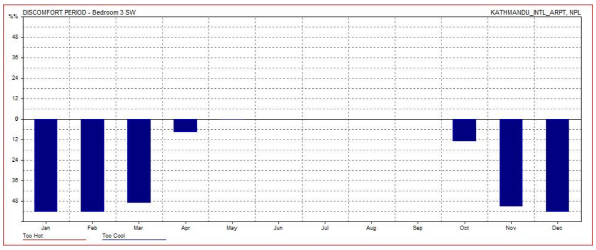


Figure 16: Monthly discomfort of Top bed room

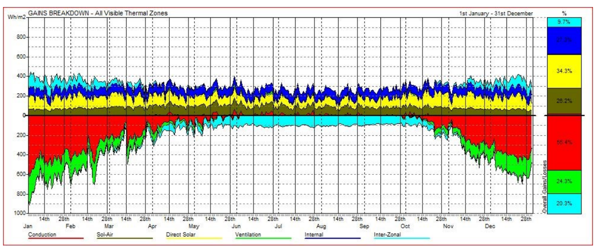


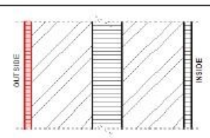
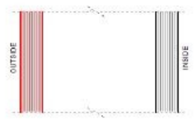
Figure 17: Passive gain breakdown under natural ventilation for Type A

The graph shows that conduction loses the most heat, at a rate of 55.4%, compared to other processes like ventilation, which loses 24.2% of its heat. Similar to this, Direct gain contributes to the largest amount of heat gain 34.3% followed by internal zonal by 27% respectively.

Proposed Scenarios Analysis:

For housing type B- Altering 230 mm brick walls with Cavity walls +Double glazed windows- Scenario -3. The 50mm air cavity between two 110 mm half brick walls is used in scenario 3 in place of the 230mm outer brick wall & 110mm interior wall. Additionally, the double-glazed low-e aluminum window replaces the single-glazed aluminum frame.

Table 3: Building Components at Scenario-3 & U-Value calculation

Building Component	Cross section Detail	U-value (w/m2-k)
External and internall wall: 101 mm brick work both sides separated by 50 mm air cavity gap.		0.77
Window: double glazed Low-e Aluminium		1.6

Percentage of time that is too hot 24% & percentage of time that is too cold is 85%.

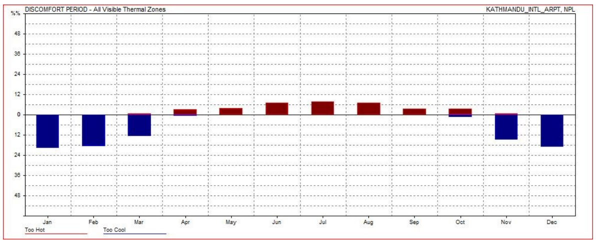


Figure 18: Monthly discomfort in all visible zones

Percentage of too hot 2.5% &percentage of time that is too cold is 104%.

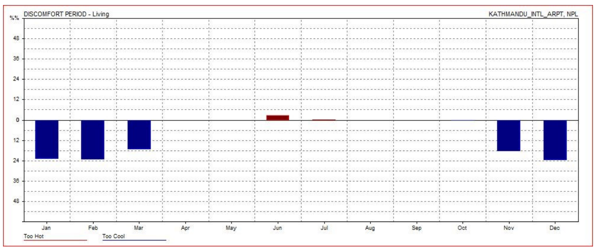


Figure 19: Monthly discomfort in Living room

Percentage of time that is too hot 0% & percentage of time that is too cold is 208 %.

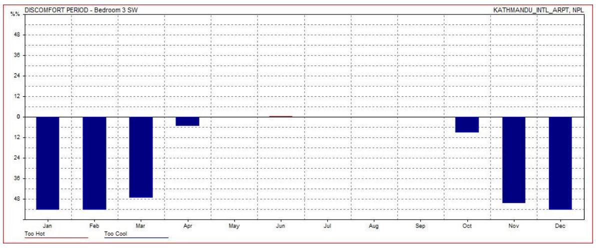


Figure 20: Monthly discomfort of Top bed room

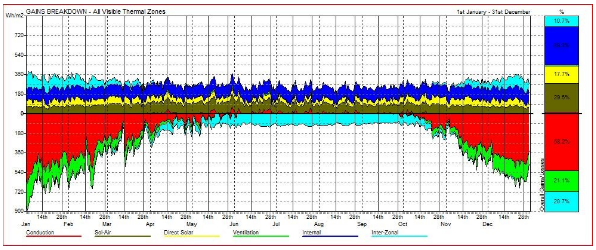


Figure 21: Passive gain breakdown under natural ventilation for type B

The graph shows that conduction loses the most heat, at a rate of 58.%, compared to other processes like ventilation, which loses 21.1% of its heat. Similar to this, Direct gain contributes to the largest amount of heat gain 17.7% followed by internal zonal by 39% respectively.

7. Finding & Discussion

The comparison of the improved model scenario with that of the basic case model is shown in the bar chart. it demonstrates that, when the base model 's building envelope is changed, replacing the outside & interior brick walls with CSEB & 50mm walls. According to the simulation's finding, the optimized model in scenario 2- CSEB & Scenario 3- Cavity wall, outcome demonstrates the cavity wall replaced with burnt brick walls provides the least discomfort degree hours. this also explains scenario 3 of the simulation for dwelling type B, where there is a higher level of comfort & clear correlation between that with a lower likelihood of energy use for heating or cooling the dwellings every year.

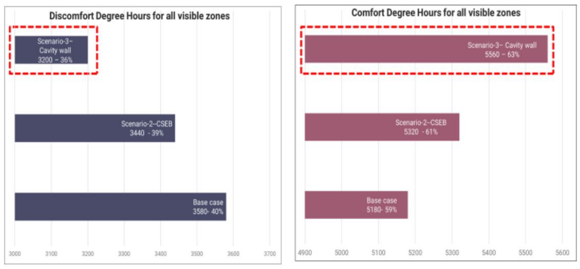


Figure 22: Comparison of the improved model scenario 3 better than that of the basic case model

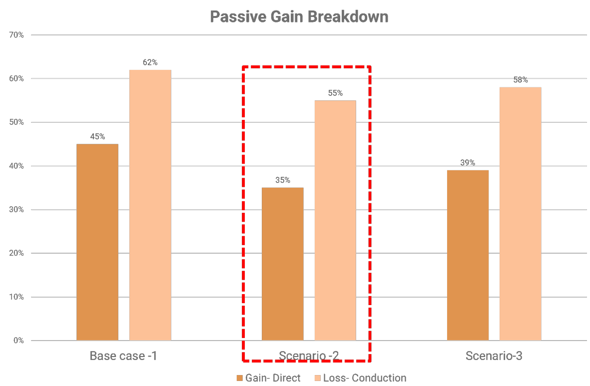


Figure 23: Comparison of the Passive gain Breakdown with basic case model- CSEB provides the least heat gain & loss

BD with energy-efficient implementation in the model homes

For this research elements of Biophilia elements like daylight, air, plants, & water were incorporated through into the buildings in the form of windows, skylights, green walls, vegetation. This research takes into consideration energy-efficient design strategies, including those that lower the HVAC load while assuring optimal energy usage. The techniques include insulation, optimal skylight utilization, & WWR. The strategic approach takes into consideration factors like how daylight availability can be incorporated into a building through windows & skylights & its effects on energy design strategy, how natural air can have an impact on a building's design that improves both human health & the overall influence on the energy consumption.

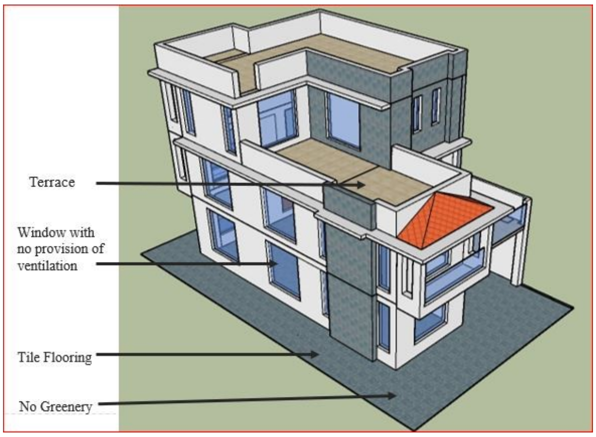


Figure 24: No Biophilic components in the base case

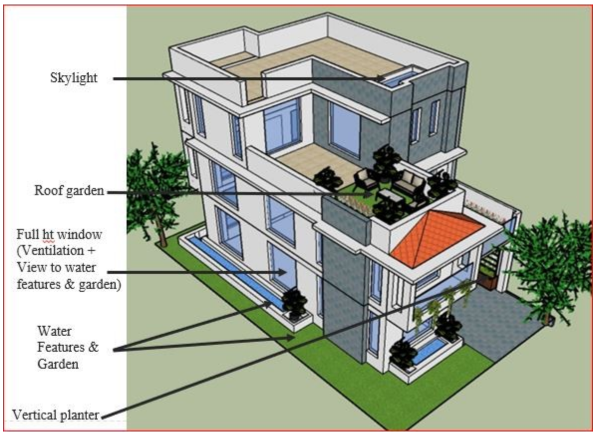


Figure 25: Implementing BD -daylight, ventilation, & vegetation results in an improvement above the base case

The research question was to identify the issues that homeowners face & how may they be reduced utilizing biophilic design & energy-saving strategies & find the possibilities for improvement in terms of energy usage & reconnecting homeowners back to nature.

8. Conclusion

Understanding the implications of bringing nature into building design to ensure human comfort while also enhancing energy performance was the key research objective. For the current study, daylight, ventilation, & plants have been taken into consideration. These elements are included since they lean more in the direction of a close connection with nature. For this goal, it was determined what problems homeowners had with relation to thermal & visual comfort & potential improvements were suggested that could be mitigated by using biophilic design & energy-saving techniques.

The study's conclusion presents a quantitative examination of the enhanced building performance while also assessing the suggested biophilic strategies. Out of the two situations, Scenario 3 displays the fewest discomfort hours, 40% to 36%, indicating that the ratio of comfort hours to comfort hours is 59% to 64%.

9. Recommendations

The literature, observation, & key informant opinions all supported the recommendations. The analysis yields the following suggestions, which are listed below:

- Energy will be saved by 37% to 40% if the building envelope is well insulated to a level that is cost-effective, or roughly 0.40 W/m2K.
- use materials with limited thermal capacity or heavy outside walls that have an 8-hour time lag.
- WWR – South facing 40-60% ideal, North facing 10-20%
- Enforce mandatory energy-efficient building standards for dwellings
- Initiate Pilot projects energy efficient buildings– like offices, schools, housings-
- Tax deduction or subsidy programs
- Launch Regular training on building methods such as CSEB, double wall air cavity construction & insulation materials
- Informing the general public about biophilic & energy-efficient practices.

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