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# Biomimicry Inspired Concept of Multi-Layer Skin and Jaali Extracted from Vernacular Buildings for Energy Efficient Building Envelope

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**Abstract**

Biomimicry is a new perspective on the nature that contributes in making the built environment resemble living organisms in many ways. Building envelope is a subdivision of biomimetic that surrounds the entire building's exterior serves as the structure's line of defense against outside forces that could affect every part of the surroundings. Around the world issues with climate change, environmental problems and energy resources crises have posed numerous challenges. Therefore, a new trend of energy efficiency is established to demand sustainable solutions which could get along with the natural ecosystem and solve manmade problems. The study is concerned with engaging biomimicry in building envelope, which offers a high potential to reduce energy demand, through accessing current scenario of building in Terai region of Nepal in terms of heat control. The main aim of this paper is to investigate how energy efficiency can be obtained by using vernacular element in building envelope which mimics nature. This study used both qualitative and quantitative methods which included observation of the vernacular, old and modern buildings of Biratnagar in the field followed by the questionnaire survey to determine the preferred parameters of biomimicry/biophilia. The identified parameters were, then used as inputs for energy modeling. The proposed bio-mimicked envelope reduced 13.25% total load. The study concludes that there is good chance for architects and designers to find sustainable solutions in the vernacular architecture which already consists of biomimicry ideas.

**Keywords**

Biomimicry, energy efficiency, building envelope, nature-inspired, vernacular

## 1. Introduction

The building represents a great environmental challenge as they are globally chargeable for 20- 40% of energy consumption for heating and cooling the inner space. In Nepal, 89% of the total energy consumption of national consumption accounts for the energy consumption by residential buildings (WECS, 2010) . Therefore, a new trend of energy efficiency is established to demand sustainable solutions which could get along with the natural ecosystem and solve human problems. The energy consumption is increased due to the poor building envelope of the residential buildings. In the current state of the economy, climate change, unstable energy supply, and growing energy prices, there is a search for solutions to improve the energy efficiency of buildings.

A major paradigm shift is taking place in design and material science for the sustainability of buildings which lead us towards biomimicry. Inspiration from nature helps to find ways for safeguarding the biodiversity and biomimicry principles provide guidelines for improving energy efficiency in the building by improving the building envelope. Nature has determined what is efficient, effective, and enduring. Janine Benyus made Biomimicry popular where Bio means "life" and "Mimesis" means to imitate.[1] The plants and animals found in nature consists of several adapting capabilities so in our mission to create sustainable built environment it makes sense to study natural organisms and mimic useful treatments to create energy efficient buildings. It is based on what we can learn from nature instead of what we can extract from nature. In the present context, there aren't many designs that have pursued

to use nature's patterns to solve artificial design issues with an appreciation on the environment.

The use of efficient design helps to reduce the energy consumption of the building in its lifecycle. One of the important concerns for designing energy-efficient buildings is their building envelope. Throughout the globe, a large quantity of primary energy is wasted because of the inefficient design of building envelopes which is not compatible with their environment. The envelope of the building has the capability of improving the building's performance in managing heat transfer, natural ventilation, redirecting, and filtering daylight, and improving occupant wellbeing. Biomimicry aims to minimize the negative consequences of built architecture on the environment in terms of energy and material use.

## 2. Method of study

.In this research, nature mimicked cooling design strategies are suggested considering simple modifications of building envelope configurations that can be applied easily in the context of Terai region of Nepal. First of all, different international and national journals, books, papers have been reviewed to explore thermal comfort and proper design of biomimicry and its strategies with their influence on building envelope. The case studies of different levels and approaches of biomimicry was carried out in three categories; executed projects, experimental model and design concepts.

Then the questionnaire survey is conducted to know the knowledge about nature inspired building and preferences of biomimicry/biophilic parameters in built environment. where participants were professionals and residents of the study area. The climatic data of Biratnagar from Department of Hydrology and Metrology was collected for the climatic analysis. The envelope composition, occupancy, and equipment of use, orientation and data essential for energy modeling were collected during field visit. The collected data were analyzed in Autodesk Ecotect Analysis 2011 software, which is a thorough concept to detail sustainable design analysis tool that offers a wide variety of simulation and analysis as well as aids in visualizing and simulating the performance of a building model in relation to its surroundings. The assessed data were calibrated and the results and findings were drawn through energy simulation of different scenarios. The conclusion based on findings has been drawn and different biomimicry techniques based on literature and field study has been suggested. Finally, the recommendations at different levels for further works has been suggested.

## 3. Biomimicry and energy efficiency

In architecture, designing an energy-efficient building that meets the thermal comfort requirements of residential buildings is a great challenge. Biomimicry can offer several solutions to the way we design architecture, including the efficiency of structures, material manufacturing, control of the thermal environment, and energy production.

### 3.1 Concept of biomimicry

Since the early ages of the built architecture, the human has tried to adapt the harsh environmental circumstances of the hot and humid climate by offering an architectural space that is relatively a thermally comfortable environment to occupants. There are new contemporary cooling strategies and solutions for the indoor environment in the hot summer sessions such as using phase change material, structure insulation panels, and bio-based insulation material.

The plants and animals found in nature consists of several adapting capabilities so in our mission to create sustainable built environment it makes sense to study natural organisms and mimic useful treatments to create energy efficient buildings.[2] Biomimicry encourages to view nature from the prospective of how to learn from nature as a valuable source rather than how to extract from it.[3] In describing to the nature as a perfect and sustainable basis for stimulating ideas, Benyus (1997) said "living things have done everything we want to do, without guzzling fossil fuel, polluting the planet, or mortgaging their future." [1] When addressing a design issue, there are three main levels of Biomimicry that may be applied in a design process.

The three levels of biomimicry are; the organism, behavior and ecosystem. The organism level refers to an organism which may include a component or whole which might be mimicked. The behavioral level interprets the behavior or response in of an

organism to a precise context and therefore the eco-system level explains the mimicking of the function of a full eco-system. There are an extra five potential mimicry dimensions for each of these tiers. The design may also be influenced by biological principles in terms of shape, material used, construction, processing, or purpose.

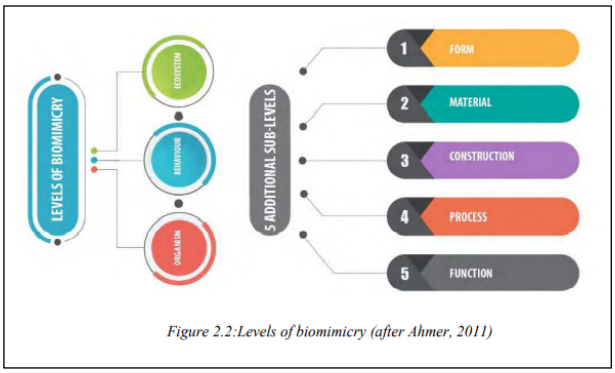


**Figure 1:** Levels of Biomimicry [2]

There are primarily two approaches of Biomimicry which plays a critical role in design. The first approach is 'Design to Biology' (Problem based approach), it recognizes human problems and explores for ways through which a human can solve the problem through it. The second is 'Biology to Design' (Solution based approach), it defines an explicit function or property of any organism or ecosystem and turns it into a design.

### 3.2 Biomimicry in building envelope

Building envelope is one of the key concerns while designing energy efficient buildings because it has the capability of improving the buildings performance in natural ventilation, managing heat transfer.[4] In order to enhance and develop building envelope's efficiency, energy efficient building envelope functions should be identified accurately and clearly. The concepts of nature inspired building envelope are adaptability, multi-ability and evolvability. The criteria such as how organisms heat, cool, give shade and regulate light should be taken into consideration when designing an energy efficient building envelope.
In order to understand the role of building envelope in reducing energy consumption through a biomimetic approach, several researchers have conducted analytical study of different case studies in which Biomimicry has been applied on different levels to understand and analyze different strategies applied in building envelope. Nour ElDin. N. (2016) followed the approach which mimicked the nature by looking into its system and process and his study emphasizes that integrating biomimicry within building envelope requires the approach at the primary stage of design.[5] Sahar Mohamed Abd El-Rahman (2020) inspired by adaptation of plants to environment developed a conceptual biomimetic model of adaptive envelope.[4] (Bhiwapurkar, 2017) conducted simulation research on solution-based approach of biomimicry whose result showed 39% of total energy decreased.[6] Architects tend to revive the passive techniques from the historical and vernacular architecture to create human comfort. Vernacular architecture in the hot and humid climate is basically designed to; delay heat transfers to indoor spaces, avoid the sun intensive radiation, enhance air flow for natural ventilation, and cool air through planting and water evaporation. The vernacular houses of Terai region were generally designed to keep the houses cool in summer as the city has hot climatic feature.

## 4. Research Context

In order to understand the existing residential building construction technology, materials and vernacular and contemporary architectural styles in case of Biratnagar, the selection of the buildings to study was based on the most practiced building type among residential area.

### 4.1 Climatic analysis

The bioclimatic chart was developed on the extracted temperature data from the department of hydrology and meteorology. These climatic data help to prepare bioclimatic chart which check out the thermal comfort level at that region.

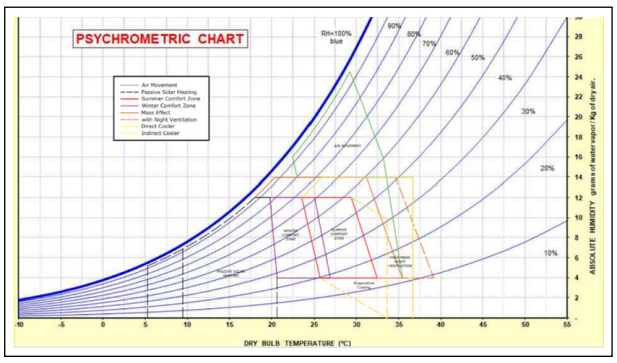


**Figure 2:** Bioclimatic chart of Biratnagar

Maximum and minimum temperature of Biratnagar

ranges from Max 29.9°C in summer and Min 15.9 °C in winter. From the analysis, daytime of three months January to March falls under comfort zone and air movement is needed in the daytime of June to October as humidity maybe a problem when it exceeds above 70%. The heating and cooling units, passive solar, ventilation and artificial devices may require for the building. The vernacular techniques may be modified to get energy efficiency in building through modern practice and approach.

## 4.2 Biomimetic analysis

Through the perception of biomimicry and biophilia, the solutions that have been tested for centuries in vernacular houses still exist in the terai region of Nepal. Vernacular building design holds knowledge, local solutions repeated over centuries are good and proved to be efficient. The solutions are tested over time and only the best is kept and copied. The vernacular architecture of houses in Terai region was generally designed to keep the houses cool in summer as the region has a hot climatic feature. Most of the vernacular architecture consists of the houses built by the Tharu people, they are low raised, identical, mostly single storied with slope roofs and are elongated.

### 4.2.1 Multi-layered skin

Inspired by the aesthetic and function of bark which protects and houses the tree a multi layered skin is developed in vernacular architecture. The bark in the envelope was conceived as a second skin or protective layer assisting with the natural ventilation of the wet area spaces.

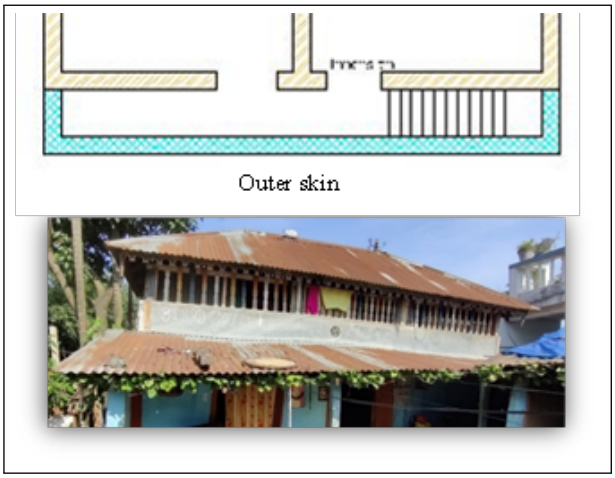


**Figure 3:** Multi-layer skin of building

The bark consists of two main layers, the outer and the inner bark. The outer bark consists of dead cells and forms the first line of protection between the inner bark's vital structure and the surrounding environment. The inner bark or phloem actively contributes to the tree's life processes. These outcomes contribute to the tree's adaptation towards the sun by providing shade. Conceptually, this notion developed into the facade becoming analogous to an 'inhabited skin', or a traditional veranda.

### 4.2.2 Jaali

As discussed earlier, the building can be protected from the environment by a multi-layer envelope and "Jaali (a perforated screen)" is a vernacular building element mostly used for openings. Inspired by biological skins of plants, animals and human which can breathe and form of the honeycomb. The jaali thus, serves three functions for the building- air, light and privacy. Jaali is able to reduce the amount of direct sunlight, which reduces the amount of heat that can enter a space. It also permits air circulation for ventilation and cross wind. Jaali divides the complete area of a standard window, measured in square meters, into a number of tiny holes.

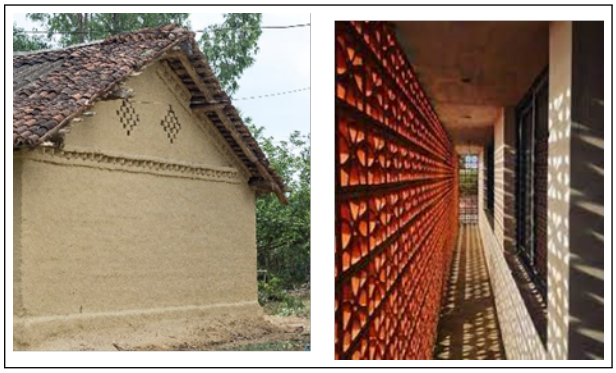

**Figure 4:** Jaali used in building envelope

## 5. Energy Modelling

Building simulation was done using Autodesk Ecotect Analysis software version 2011. The base residential buildings were divided into different zones and the building activity was chosen as per the zone. The general setting used are as follows: 1. Clothing: Shorts and t-shirts, 2. Humidity: 65%, 3. Air Speed: Pleasant Breeze (0.5m/s 2), 4. No. of people: Dependent upon the room, 5. Activity: sedentary, 6. Air change rate: Average 1 air change per hour, 7.

Wind Sensitivity: Reasonably protected 0.25 air change per hour 8. Active system: Natural ventilation, 9. Comfort band: 18-27°C.

**Table 1:** Specification of vernacular building

| SN | Building elements | Description |
|---|---|---|
| 1 | Plinth | 15" soil compaction with 1" mud plaster |
| 2 | Wall | 2" bamboo/wood and 1" mud plaster on either side |
| 3 | Roof | Thatch |
| 4 | Door | Timber |
| 5 | Windows | Timber/bamboo |

**Table 2:** Specification of old existing building

| SN | Building elements | Description |
|---|---|---|
| 1 | Plinth | 15" soil compaction with 1" mud plaster |
| 2 | Wall | 14" brick wall and 1" mud plaster on either side |
| 3 | Roof | CGI sheet |
| 4 | Door | Timber |
| 5 | Windows | Timber/bamboo |

**Table 3:** Specification of modern building

| SN | Building elements | Description |
|---|---|---|
| 1 | Plinth | 6" brick soling with 2" PCC and ceramic tile |
| 2 | Wall | 9" brick wall and 1" cement plaster on either side |
| 3 | Roof | Tiles on concrete |
| 4 | Door | Timber |
| 5 | Windows | Timber |

In order to conquer the objective of the study, a typical vernacular building, existing old building and modern building was purposefully selected from the study area. The comfort level in those residential buildings, monthly discomfort loads were calculated for thermal analysis. For building modeling, different scenarios were created by adding and altering biomimicry strategies.

## 6. Result and discussion

In this study, different scenarios are taken and our main focus is the heating cooling of the three types of buildings selected from study area. Upon evaluation of heating cooling obtained from simulation the following results has been obtained through analysis of all visible thermal zones. The overall outcome/ comparison (Heating/ Cooling Load) of the three types of building found in Terai region of Nepal is as follows:

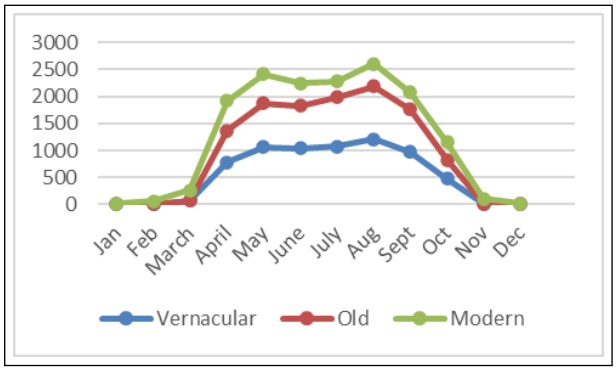


**Figure 5:** Comparison of summer discomfort hours

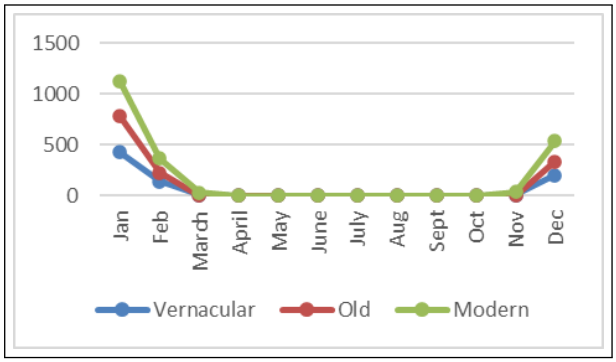


**Figure 6:** Comparison of winter discomfort hours

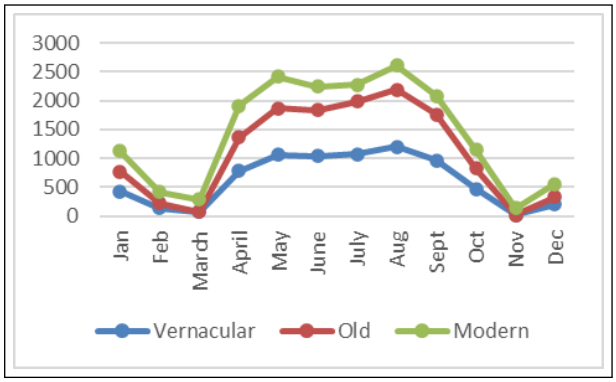


**Figure 7:** Comparison of total discomfort hours

The aforementioned comparison indicates that the

envelope of vernacular building is more effective to maintain thermal comfort in comparison to other existing old building and modern building.

### 6.1 Proposed Envelope

The building envelope is understood as a system which can be transformed according to several incentives. The enhancement of air movement is essential for the Terai region of Nepal. The biomimicry design leads to a comfortable breathing house that means the building envelope is rather permeable and enhance natural ventilation. Furthermore, working on proposed scenarios; our main focus is the heating cooling of the proposed modern residential building in context of Biratnagar by using the biomimicry inspired concept of multi-layer skin and jaali extracted from vernacular buildings.

**Table 4:** Specification of proposed case scenario 1

| SN | Building elements | Description |
|---|---|---|
| 1 | Plinth | 15" brick soiling with 1" cement plaster |
| 2 | Wall | Inner layer - 9" brick wall and 1" cement plaster on either side Outer layer – 4" brick wall of jaali design |
| 3 | Roof | Concrete slab |
| 4 | Door | Timber |
| 5 | Windows | Timber window + ventilations |

Upon evaluation of heating cooling load obtained from simulation of the considered test scenarios the following results have been obtained.

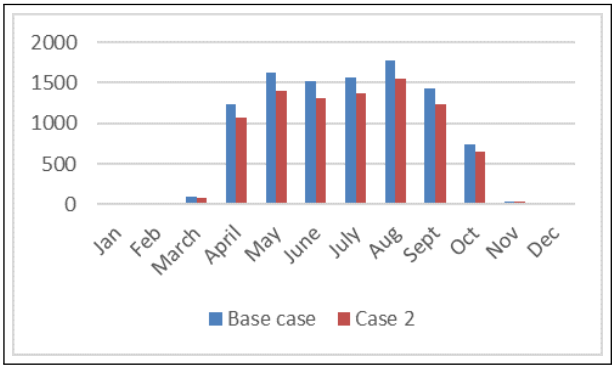


**Figure 8:** Comparison of summer discomfort hours

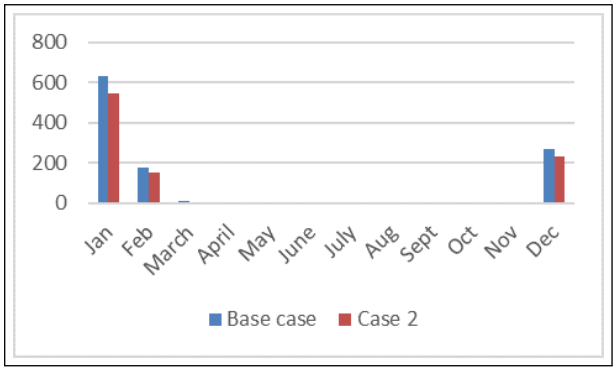


**Figure 9:** Comparison of winter discomfort hours

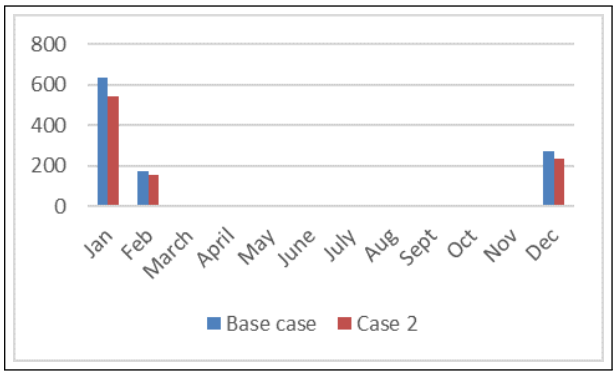


**Figure 10:** Comparison of total discomfort hours

The aforementioned comparative charts indicate that there is substantial improvement in the heating and cooling due to the implementation of the proposed scenarios. By which, 13.25% reduction in total load is seen.

## 7. Conclusion

Building envelope contains significant amount of energy uses and by discovering and emulating nature's strategies the energy consumption for creating thermal comfort was decreased by applying biomimicry approach. This study presents the development of design method based on nature inspired design principles that has been applied in vernacular architecture of the study area. The proposed base model and biomimetic envelope using multi-layer skin and jaali concept has come up with the certain result in support of the research. Adopting combination of both the strategies the total discomfort in proposed base case is 11107 DegHrs and proposed scenario 1 is 9636 DegHrs by which total discomfort hours reduction is 13.25%.

Architects and designers can learn from nature in

order to propose technical solutions to solve human problems in built environment so in order to gain more thermal comfort, further research with focus on active heating/ cooling systems which helps to mimic the behavior of natural organisms and their efficiency is required.

## References

[1] Janine M Benyus. Biomimicry: innovation inspired by nature, 2021.

[2] Ar KuldeepK Bhatia and Ar Deepali K Hejib. Biomimicry: Architecture follows nature.

[3] Heba Mansour. Biomimicry a 21st century design strategy integrating with nature in a sustainable way. *BUE, FISC*, 12, 2010.

[4] Sahar Mohamed Abd El-Rahman, Sobhy Ibrahim Esmail, Husam Bakr Khalil, and Zeinab El-Razaz. Biomimicry inspired adaptive building envelope in hot climate. *Engineering Research Journal*, 166:30–47, 2020.

[5] N Nour ElDin, Ab Abdou, and I Abd ElGawad. Biomimetic potentials for building envelope adaptation in egypt. *Procedia Environmental Sciences*, 34:375–386, 2016.

[6] Daphne Fecheyr-Lippens and Pravin Bhiwapurkar. Applying biomimicry to design building envelopes that lower energy consumption in a hot-humid climate. *Architectural Science Review*, 60(5):360–370, 2017.