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Dromedary Camel: A Biomimetic Approach for Improving Energy Efficiency in Desert Buildings: A Case Study in Sinai

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ABSTRACT

Nature inspires architects, allowing them to generate ideas and respectively handle the architectural challenges. Biomimicry serves as an empirical illustration of this inspiration in architecture. This study examines the application of biomimetic science in the design and creation of an architectural products that are suitable for the desert environment and are able to integrate seamlessly into the desert ecosystem at El Arish, Egypt. Biomimicry offers architects a powerful tool for creating buildings that are not only environmentally friendly and resource-efficient but also aesthetically pleasing, functional, and resilient in the face of future challenges. The methodology utilizes three approaches: a primary approach that focuses on biomimicry concepts, an analytical approach that focuses on the camel and its adaptations to desert conditions, and a practical approach that applies the shape and the skin camels of their in the Sinai desert to a building model. The camel employs a variety of strategies, including thermal regulation and insulation, water conservation, structural stability and load bearing, as well as mobility and adaptability. Furthermore, this study will address specific inquiries by conducting research to validate them through a practical simulation on a prototype, which simulates the camel's body as a residential building. The main result is that, energy consumption has decreased by 50% compared to the prototype temperature conditions, a thing which in turn achieves energy efficiency.

KEYWORDS: Camel, Biomimetic, Sustainable Approach, Camel's Environment, Camel's Skin, Building Simulation, Prototype simulation.

1. INTRODUCTION

Life on Earth has always been able to adjust to its surroundings. Every living thing has its own unique set of characteristics and habits that allow it to thrive in its specific ecological niche, where it can get the nutrients and water it needs to stay alive. These essentials are all what an organism need to thrive in its biological niche [1]. Over the years, urban residential areas rapid growth in hot desert hybrid settlements has led to a decline in indoor environmental quality (IEQ). This matter has led, in turn, to a decline in indoor environmental quality: that is why there is a great tendency to use green buildings. Green buildings aim to enhance efficiency by using energy resources and materials to minimize impacts on both human health and the environment over their life-cycle [2]. This highlights the necessity for solutions drawn from nature to address the challenges posed by declining indoor environmental quality (IEQ) in these contexts [3]. The variety of life forms in nature underpins the development of biomimicry science. This interdisciplinary area offers significant insights across multiple scientific fields, promoting innovation and the pursuit of sustainability goals. Biomimicry science [4] involves the study and emulation of the adaptation mechanisms, processes, and strategies employed by organisms and ecosystems to thrive in diverse environmental conditions. Biomimicry is the science that observes the form, function and ecosystem in nature and aims to produce sustainable solutions [5] for humans by imitating these designs or by taking inspiration from

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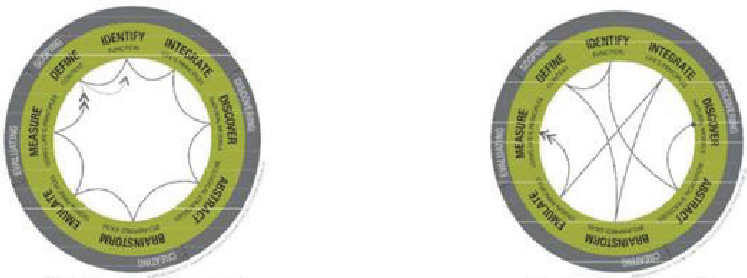
them [6]. Architecture is a famous practical application of biomimicry science. Biomimetic architecture exemplifies a sustainable design [7] methodology that derives inspiration from natural models, systems, and processes [8], incorporating them into the constructed environment.

Biomimetic architecture employs two methodologies: using biology as a design influence and employing it as a design reference [9]. The initial approach to design relies on biological or ecological expertise rather than explicitly delineating the design process itself [10]. Typically, the types derived from this biomimetic classification are copying a shape, a process, or an ecosystem's level [11]. Still, we need more biological studies to confirm that this information works in the design setting. The second technique is widely used in biomimicry. Representation occurs when humans initially recognize their demands or design challenges and subsequently seek out how creatures and ecosystems address comparable difficulties [12]. But Oguntona [13] classified a problem-based approach and solution-based approach, as shown Fig. 1 [14]. It is represented when humans first identify their needs or design problems and then look for how organisms and ecosystems solve similar issues. Camels are called the desert ship [14, 15] because they have been considered the only food and transportation provider for humans in arid and semi-arid areas for hundreds of years. The one-humped (dromedary camel) and the two-humped (Bactrian camel) camels combine high temperatures and low water use, challenging our preconceived notions. Both species can withstand extreme weather conditions; the first lives in deserts, whereas the latter inhabits cold and arid regions.



Problem-based Approach   Solution-based Approach

Fig.1: Biomimetic Architecture Approaches [14].

1.1. Importance of Energy Efficiency in Desert Environments

Energy efficiency holds significant importance in desert environments due to several factors:

a) **Resource Conservation**: Arid zones often face constraints in accessing resources like water, fuel, and electricity. Enhancing energy efficiency aids in preserving these resources, ensuring their availability for vital requirements while alleviating pressure on arid ecosystems.

b) **Cost Savings**: For individuals and communities living in dry regions, the best way to save money on utility bills is to maximize energy efficiency. Considering the high energy requirements for cooling, lighting, and water supply in dry regions, implementing energy-efficient measures might result in large cost savings over time. [17].

c) **Environmental Sustainability**: Arid ecosystems are especially susceptible to the repercussions of climate variations and human interventions. This happens by curbing

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energy usage and the ensuing greenhouse gas discharges, energy efficiency campaigns assist in curbing environmental deterioration, safeguarding biodiversity, and fostering ecological equilibrium in arid settings [12, 9].

d) **Climate Resilience**: The design strategies and building practices that aim to make structures and communities more adaptable, resistant, and able to recover from the impacts of climate change and extreme weather events [18], enhance the long-term sustainability and livability of the built environment.

e) **Public Health and welfare**: Sustaining pleasant indoor environments is crucial for the welfare of inhabitants in arid societies. To maintain such an environment, energy cooling mechanisms and architecture layouts are used to regulate indoor temperatures and enhance air quality [19].

f) **Economic Development**: Channeling resources into energy efficiency ventures catalyzes economic expansion and employment opportunities in arid zones. This encompasses prospects in renewable energy advancements, energy-conserving technologies, eco-friendly architectural blueprints, and associated sectors, nurturing local job markets and economic well-being [17].

1.2. Significance of Biomimicry in Architectural Design

The importance of biomimicry in architectural design is apparent in its ability to transform our methods of building design, construction, and operation [20]. In addition to sustainability, which considers nature's efficiency and incorporates sustainable strategies [21], innovation [22] aimed at enhancing the functionality and efficiency of new building techniques and materials, and resilience to adapt to changing environmental conditions, such as climate change, extreme weather events, and resource shortages [23]. A good example of this is biophilic design, which aims to reconnect people with nature through the built environment and has demonstrated that integrating elements like natural light, greenery, and natural patterns into building design through biophilic architecture enhances human health and resource efficiency. Biomimetic designs are often characterized by their ability to optimize resource use by mimicking natural processes and structures [1]. It can be resulted in buildings that consume less energy for heating, cooling, and lighting [24], as well as a reduction in water consumption and waste materials. The key aspects of significance regarding energy efficiency in arid conditions are illustrated in Fig. 2.

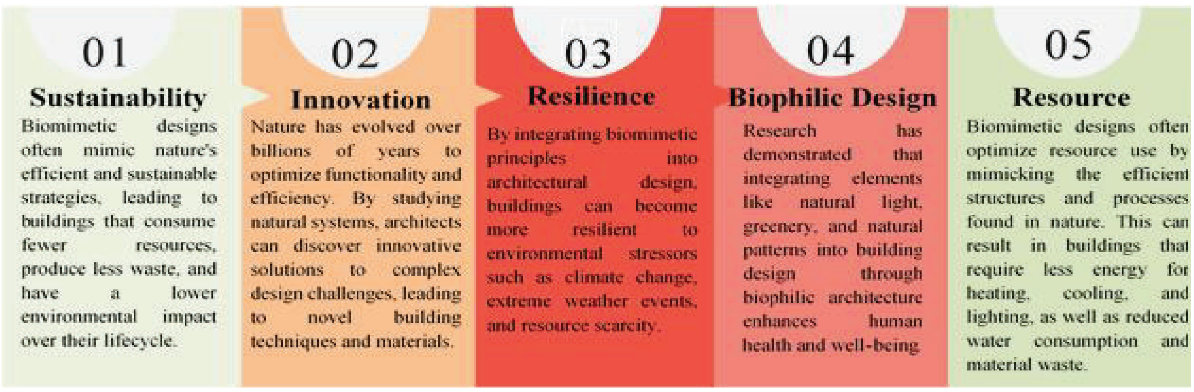

Fig. 2: Key points of significance in energy efficiency in desert environment.

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2. OBJECTIVES OF THE RESEARCH

The study aims to:

1. Apply biomimicry concepts to the desert buildings in Egypt.
2. Identifies and implements innovative tools and systems that can effectively adapt the building to its hot environment.
3. Analyzes the camel's thermal regulation and insulation, water conservation, structural stability, load bearing, mobility, and adaptability.
4. Utilizes camel strategies to enhance the energy efficiency of residential buildings.

3. METHODOLOGY

The methodology of this study depends on three major approaches: the primary approach which focuses on biomimicry concepts, the analytical approach which focuses on the camel and its adaptations to desert conditions, and the practical approach which focuses on the camel mechanism on building models, as shown in Fig. 3.

Fig 3: Illustrates the methodology of three approaches.

3.1. Camel Adaptations Relevant to Desert Building Design

The camel's most distinctive adaptation is its hump, which stores fat that can be metabolized into energy and water during periods of scarcity. Camels have specialized kidneys that enable them to reabsorb water from urine, resulting in highly concentrated urine and reduced water loss. Their nostrils can close to prevent sand from entering the respiratory system during sandstorms, and they possess long eyelashes and an extra eyelid to protect their eyes from sand and harsh sunlight.

Camels are highly efficient at conserving water and capable of surviving for extended periods without water. They can tolerate dehydration by losing up to 25% of their body weight in water. Their ability to extract moisture from the vegetation they consume, along with their efficient water reabsorption mechanism, contributes to their water conservation strategies. Camels have a thick coat of fur that insulates them from both extreme heat and cold, helping to regulate their body temperature. They can tolerate wide fluctuations in body temperature, allowing them to adapt to the temperature extremes in desert environments. Camels are adapted to feed on tough, thorny desert vegetation thanks to their tough, leathery lips and specialized

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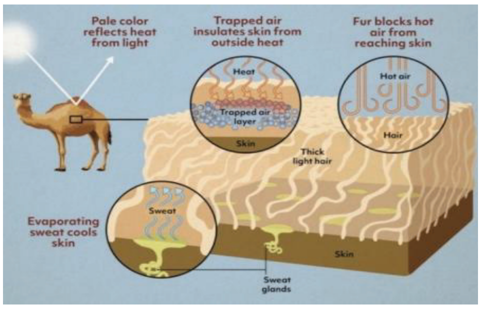
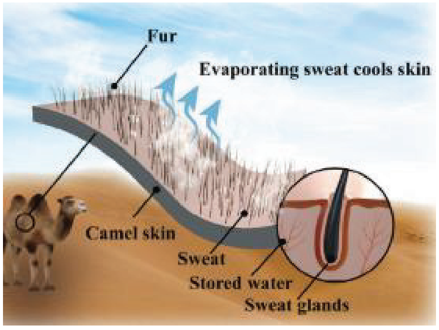
palate, which enable them to consume a wide variety of plant species. They can also efficiently extract nutrients from sparse vegetation, making them well suited to desert diets. Camels have long legs and padded feet, which help them traverse sandy terrain with ease. Their ability to travel long distances without water and withstand high temperatures makes them valuable transportation animals in desert regions.

a) Thermal Regulation and Insulation

The Dromedary Camel possesses sophisticated thermal regulation mechanisms that are critical for desert survival. Its thick coat of fur provides insulation against temperature extremes [25], aiding in heat retention during cold nights and heat dissipation during scorching days. Additionally, camels possess specialized sweat glands that minimize water loss during perspiration, allowing them to maintain thermal equilibrium more efficiently in arid environments [26], as shown in Fig. 4.



(A)



(B)

Fig. 4: Camel's fur coat slows heat gain in three primary ways; A- combined with cooling from evaporating sweat, B- The evaporative cooling of camel [25].

b) Water Conservation Strategies

Camels are renowned for their exceptional water conservation abilities, making them well suited for desert habitats. Their highly efficient renal system enables the reabsorption of water from urine, resulting in concentrated urine and reduced water loss. Furthermore, camels can tolerate dehydration by temporarily storing water in their body tissues, particularly in their humps, and metabolizing fat reserves into water, when necessary, thus extending their endurance without access to water sources [27].

c) Structural Stability and Load Bearing

The anatomical structure of camels is optimized for traversing sandy desert terrain with stability and endurance. Their long legs and wide, padded feet distribute weight evenly, minimizing sinking into loose sand and enhancing stability during locomotion. Moreover, camels possess strong, flexible spines and robust skeletal structures that contribute to their load-bearing capacity, enabling them to carry heavy loads over long distances with minimal strain [28].

d) Mobility and Adaptability

Camels exhibit remarkable adaptability to diverse desert landscapes, owing to their anatomical features and behavioral characteristics. Their elongated limbs and flexible joints facilitate efficient movement across uneven terrain, while their large, cushioned feet provide

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traction and shock absorption. Additionally, camels display behavioral adaptations such as seeking shade during the hottest parts of the day and adjusting their feeding and resting patterns to conserve energy in response to fluctuating environmental conditions. These adaptations of the dromedary camel offer valuable insights for designing buildings that can withstand the challenges of desert environments, including extreme temperatures, limited water resources [29], and unstable terrain. By emulating nature's solutions, architects can develop more resilient and sustainable structures suited for arid climates [13].

3.2. Case Study: Architectural Design Inspired by Dromedary Camel Adaptations

3.2.1. Design Principles Derived from Camel Adaptations

Dromedary camels exhibit the exceptional capacity to successfully integrate two characteristics: being active in severe temperatures and conserving water. Unlike human nature, where he can be active at high temperatures by using the sweating mechanism to regulate body temperature. This involves extracting large amounts of water for cooling, a luxury that camels often cannot afford due to their limited water resources [29]. Speculating about their origins can inspire architects, particularly to develop innovative strategies and systems for their survival in hot, arid regions. According to extensive research, camels possess numerous superior characteristics that enable them to thrive in their harsh environment.

3.2.2. Integration of Biomimetic Solutions into Building Design

a) Camel Form

The shape of the building is inspired by the shape [11] of the camel's body to reduce the heat load falling on the building and its height. The body's height from the ground by its legs reduces the thermal conductivity with the ground, as shown in Figure 5. One of those characteristics is the form of the dromedary camel. Camels have a large body mass, long legs, and large humps that help in temperature regulation [30]. This is referred to that the larger the body mass, the slower the heat up. The legs and humps also give a large skin surface to the body mass. The second characteristic is its height, which is about over 2 meters from the ground. This allows the desert winds free access to his body (see Fig. 6). In dromedary camels, it appears that hydration plays a role in thermoregulation. In the absence of sufficient water, the amplitude of the camel's body temperature (the difference between its greatest and lowest values) can rise by 2°C to 6°C.

Fig. 5: Iterations to digital concept integrated design implementation with camel and building design.

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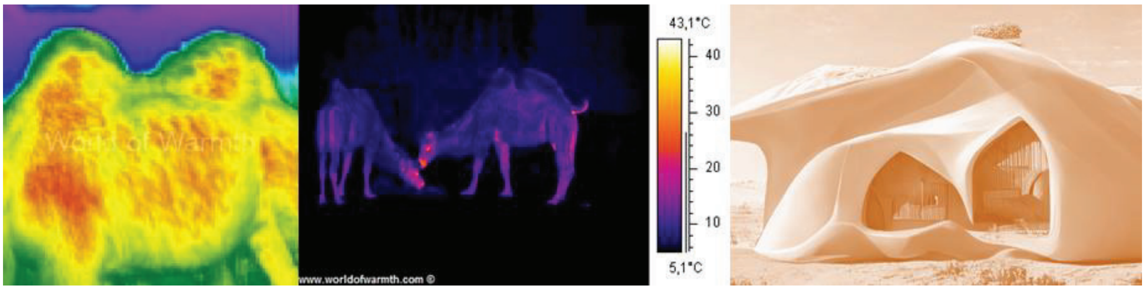

Fig. 6: The shape of the camel's body to reduce the heat load falling on it and the proposed building form inspiration in the concept stage.

[Source: https://www.worldofwarmth.com/gallery/].

b) Camel Skin

Almost all organisms, even camels, are exposed to high levels of solar radiation. To insulate the high environmental temperature, they depend on the density, thickness, texture, and color of the coat, in addition to the presence of fat layers. To many dromedaries breeds that have lived in hot, arid environments have a smooth, thin, light-colored reflective coat to effectively deal with solar rays. During hot hours, the camel does not dissipate heat by sweating to conserve water. The temperature of the body could rise to 40.7 C° and be released during the cool night to reach 34 C°. The combination of camel hair and sweat glands creates an effective mechanism for regulating temperature. Because their fur remains dry to the touch, there was a previous belief that camels do not perspire. That statement is false. The distinctive constructive collaboration between the perspiration and fur of camels is the fundamental mechanism by which they regulate their body temperature, as seen in Fig.7.

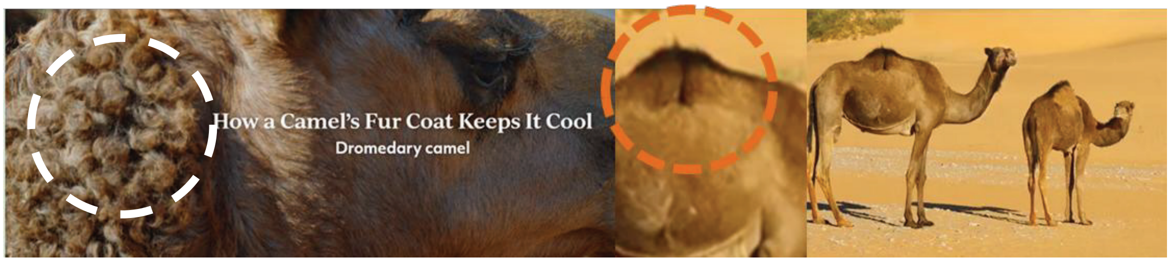

Fig. 7: Camel fur and sweat glands combine to form a powerful temperature management system.
[Source: https://asknature.org/strategy/how-a-camels-fur-coat-keeps-it-cool/].

Camels have evenly distributed sweat glands throughout their skin. These glands facilitate the removal of body heat through evaporation, similar to how it occurs in humans. Nevertheless, a layer of dense fur adorns the surface of camel skin, reaching a depth of 10 cm in certain areas. However, this fur does not hinder water evaporation. Its function is to provide insulation for the camel, protecting it from the heat that is coming towards it. The insulating properties of the camel's fur minimize the heat transmission from the heated surroundings to the camel's body through its systems. The light color of a camel's coat effectively reflects light energy, minimizing the transmission of heat to its skin through radiation. With gaps between the molecules, the trapped air in the camel's fur acts as an insulating layer, reducing the passage of heat to the skin through conduction. The individual hairs of the camel's fur hinder the flow of air, thus decreasing the transmission of heat to its skin by convection. The temperatures

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between the outside surface of their fur and their skin can reach to 30 degrees Celsius, a degree that is equivalent to the difference between a hot day and a winter day. Therefore, camels require a significantly lower amount of water evaporation from their skin to regulate their body temperature. Strategies aimed at mitigating heat absorption from the surroundings are crucial in several domains. Camel-inspired designs that integrate water-cooling with heat gain insulation can be highly efficient in all of these uses. A camel-inspired cooling system uses an aerogel-hydrogel system to efficiently chill biological materials for extended periods while consuming minimal amounts of water and energy [31]. Figure 8 illustrates this, and Table 1 summarizes it. By MIT, the cooling system consists of two levels. The inner layer consists of a hydrogel that allows for rapid evaporation of water, resembling sweat glands. The outer layer consists of an aerogel material that effectively insulates against external heat while still allowing water vapor to permeate, much like the insulating properties of camel hair [28]. Water vapor in the cooling system delays the impact of the warm ambient temperature on the contents, making the cooling effect last longer. The design of the technology simplifies the process of rehydrating the hydrogel. With a total thickness of less than 1.5 cm, the material outperforms hydrogel alone by providing cooling of almost 7 °C for five times the duration.

Table 1: Camel Skins Through Biomimicry Concept.

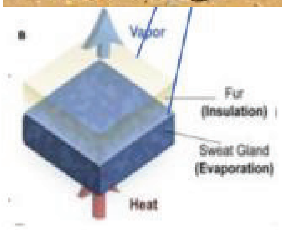
Camel's Skin	**Organism**	Camel's fur layer and its sweat glades	 
	Function	Sweat glands: Responsible for the sweating process to cool the camel's body from the inside. Fur layer: Acts as an insulating force to reduce the camel's gain of heat from the surrounding environment	
	Level	Behavior & organism	
	Dimension	Process: Sweating Function: Sweat gland Material: Fur layer	
	Application	Both the sweat glands and the fur coat simulated with materials that do the same job. The thickness of the skin at the hump is 22.65mm, while the thickness of the skin in the middle of the side is 9.56 ± 0.46 mm. The fur layer is thicker in some places (4 inches /10 cm).	

Fig. 8: Camels possess a dense covering of insulating fur that minimizes the loss of moisture and safeguards them from dehydration.

https://asknature.org/innovation/passive-cooling-system-inspired-by-camels/

https://news.mit.edu/2020/evaporation-passive-cooling-1111

[Journal article, Passive Sub-Ambient Cooling from a Transparent Evaporation-Insulation Bilayer, *Joule*]

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3.2.3. Selected Materials for Insulation in Building Design

- **Hydrogel** (coating of heat-sensitive hydrogel): It mimics the function of the sweat glands in camels. The thickness of this coating layer is 3 mm.
- **Aerogel Blankets**: These mimic the function of the fur layer in camels. The thickness of this layer is 10 mm.

c) Camel Nose

Camel's nose strategy is a new innovative architectural application for desert buildings. As the camel breathes, its nasal cavity creates turbulence as it travels through its turbinates. The moisture in the air then clings onto the interior walls, where it is absorbed [27]. The camel's nose acts as both a humidifier and a dehumidifier with every breathing cycle, as shown in Figure 9. The camel uses another principle of physics: the greater the surface area, the faster the rate of evaporation or condensation. The camel has a brain cooling system. Camels can meet part of their needs for water by condensing the water vapor which comes out with the exhaled air. When faced with dehydration in its hot and dry habitat, the dromedary camel employs two methods to preserve water via its nasal surfaces. First, it cools the exhaled air throughout the night, and second, it extracts water vapor from the exhaled air. At night, the temperatures outdoors are usually lower than the camel's internal body temperature. During inhalation, the camel's nasal tubes facilitate heat exchange between the cold outside air and the nasal surfaces, cooling the nasal surfaces and warming the entering air. The camel's respiratory system maintains the air at body temperature and retains the maximum amount of water vapor. During exhalation, the camel's heated lung air meets the cooler surfaces of its nasal passages, resulting in heat exchange. As the exhaled air cools, the water vapor condenses into liquid water on the nasal surfaces. However, the dromedary camel employs a technique to save water more efficiently: it captures water vapor from the exhaled air, reducing its humidity to 75–80%. The desiccated nasal surfaces of a parched camel are hygroscopic. This indicates their ability to assimilate and retain water molecules from the ambient atmosphere. The hygroscopic nasal surfaces collect moisture from the exhaled air and release it into the inhaled air. The dromedary camel's nasal passages have a huge total surface area of turbinate structures, which is the reason why its water recovery systems are very efficient. The spongy nasal bones found in some animals are referred to as turbines. In camels, the turbinates are intricately curled, creating small air passages and a significant surface area for the exchange of water and heat, as shown in Table 2. Measurements indicate that camels possess a nasal surface area exceeding 1000 cm2 [32]. The camel expels warm, water-saturated air to release excess body heat, although this process results in water loss [33] (see Fig. 10). The brain cooling system not only protects for the brain in extreme temperatures but also allows the camel to have a wider range of tolerance for hot conditions.

Fig. 9: Camels use their nasal hygroscopic characteristics to extract water from the air as they exhale.

[Source: https://asknature.org/strategy/nasal-surfaces-remove-water-vapor/]

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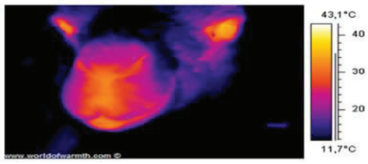
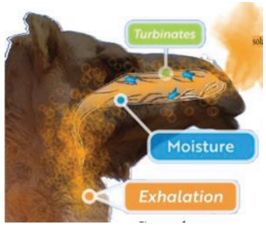
Table 2: Camel noses through biomimicry concept [27]

Camel's Nose	**Organism**	Camel's nose	 https://www.worldofwarmth.com 
	Function	The hygroscopic nasal surfaces remove moisture from the exhaled air and release it into the inhaled air.	
	Level	Behavior & organism	
	Dimension	more than 1000 cm^2 of nasal surface area	
	Application	Camel's nose strategy is a new innovative architectural application for desert buildings. **Test model:** Glass prism- painted in matter black-water collect tubes- burlap tanks –solar collector – calcium chloride	

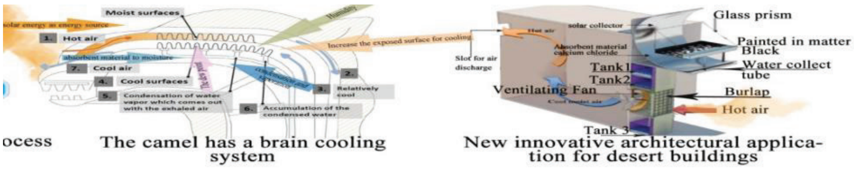


Fig. 10: Camel nose strategy [27].

3.2.4. Design Process and Implementation

A proposed building form inspired by camel form and with its skin layers for the desert building design. Such design is represented as a residential unit in a reference case study with an area of $10m \times 20\ m$ and a height of 5.20 m (duplex with mezzanine floor). Table 3 presents a reference case study in correspondence with the camel body simulation. Done on the Sinai Desert, this study reviews building design in a hot climate.

Table 3: Building specifications

Building Type		Residential unit	
Building Area		10 m x 20 m (proposed)	
Building Height		5.20 m (Duplex)	
Weather File		EL Arish, Egypt (climate studio)	
Building Location		EL Arish, Egypt	
Material of Analysis			
Material Type		**Properties Base model**	**Properties Camel's Model**
Wall	White/light tile	Reflectance 60%	U Value =.215w/(m^2.K)
Floor	Beige tile	Reflectance 33%	300 mm concrete/ 80 mm insulation
Glazed System	Single pan	Clear glass, Tvis=.8	Sungate glass (460), Tvis=.59, U V=.97
Construction	Bearing wall system	Bricks	300mm Shield concrete
Ceiling	White tile	70%, U Value =.355w/(m^2.K)	300 mm concrete with 80 mm screed insulation

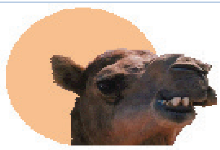
4. ARCHITECTURAL BUILDINGS INSPIRED BY CAMELS:

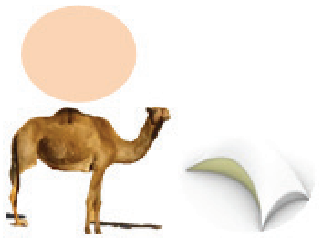
As for the second approach, the proposed design can effectively tackle the form and the skin composition of the camel and how such factors affect temperature regulation in the camel's body. Consequently, these forms can be applied to the form and the material of the buildings. To introduce the proposal design, we follow the second approach: *biology-influenced design*. Biology influenced design or the organism level in biomimetic architecture is based on the application and simulation of the camel's morphology and skin composition on buildings. The dimensions that were implemented are reform, process, and function (Table 4). A computational analysis [35] that used the Rhinoceros and Grasshopper plugins (version 6) [36] performed the model form with the Kangaroo plugin to optimize the structure based on the main wind direction and the best orientation of the model. In addition, Climate Studio assumes thermal flow and energy consumption from a compatible design model, as shown in Figs. 10 and 12.

Fig. 11: modeling of basic model vs. camel's building concept.

El Arish International Airport's 2023 weather history depicted in Fig. 12, along with other historical meteorological data sets, especially in the summer months of the year.

Table 4: Integrated camel's characteristic and design philosophy

Camel's Eyelash	**Organism**	Camel's eyelashes	
	Function	Protect camels' eyes in case of sand storms	
	Level	Organism	
	Dimension	2 rows of movable eyelashes	
	Application	-Adaptive vertical / horizontal fins -Protect building from the surrounding environment and serves as a shading device.	
Camel's Eyelid	**Organism**	Camel's eyelid	
	Function	The third lid is a very thin lid that works as a sort of "windshield wiper" to clean off their eyes.	
	Level	Organism	
	Dimension	Protect camels' eyes in case of sand storms.	
	Application	Fins are movable from side to side to save the building façade.	
Camel's Ear hair	**Organism**	Camel's ear hair	
	Function	Filter the stormy and sandy air from entering its ears.	
	Level	Organism	
	Dimension	Filter the stormy and sandy air from entering its ears.	

	Application	Filters inspired by camel ear and nose hair that filter air from sand.	
Camel's legs	**Organism**	Camel's legs	
	Function	When a camel lies down, it rests on its legs, allowing cold air to pass under the body.	
	Level	Behavior	
	Dimension	The legs help the camel to lie down as it rests on it when it lies down.	
	Application	The building is raised to a level e from the ground level, allowing the entry of cold air and expelling hot air [34]	
Camel's Form	**Organism**	Camel's form	
	Function	The external shape of the camel reduces the heat load falling on it from solar rays, while its height from the ground, which is the length of its legs, reduces heat conduction with the ground.	
	Level	Organism	
	Dimension	Form	
	Application	Simulation of the building's outer shell and height of the camel's exterior shape and height	

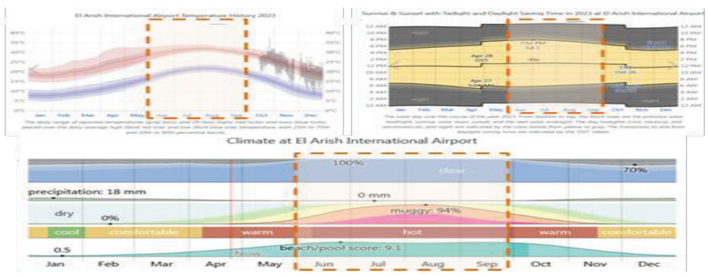


Fig. 12: Weather at summer season at El Arish International Airport (2023), Egypt

[Source: https://weatherspark.com/h/y/148674/2023/Historical-Weather-during-2023-at-El-Arish-International-Airport-Egypt].

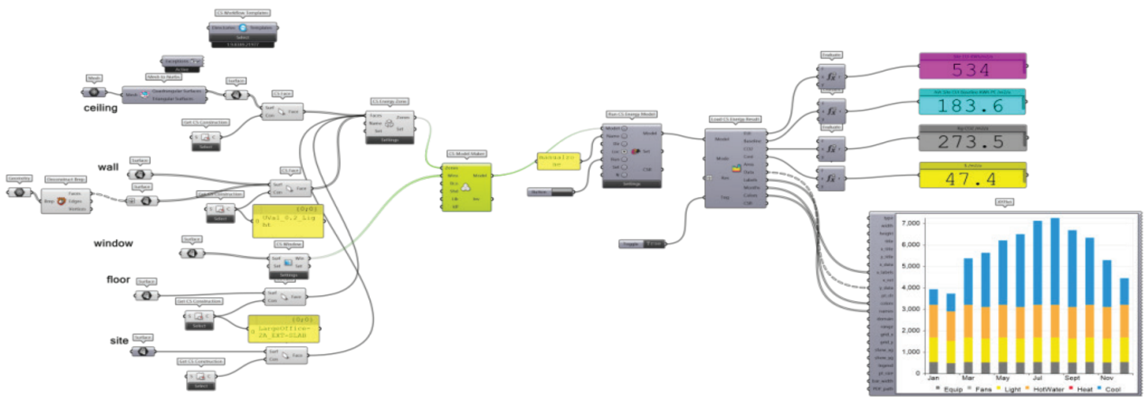


Fig. 13: Scripts of model after apply biomimicry approach by Grasshopper for Rhinoceros (v6).

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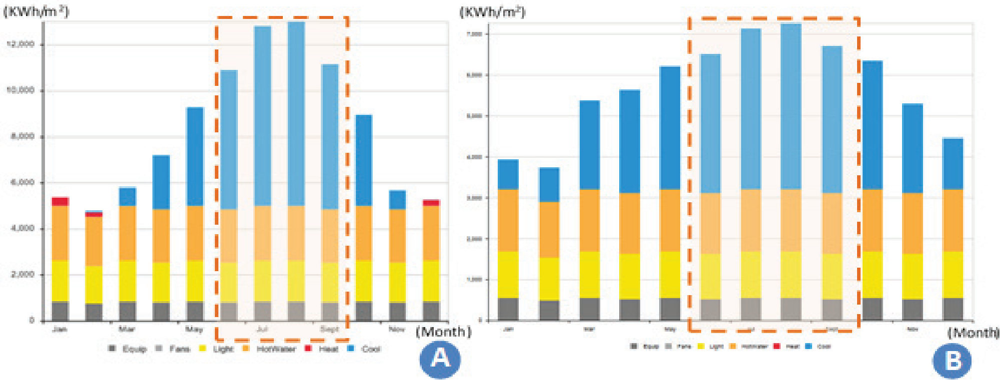

Fig. 14: A chart showing monthly energy consumption for various categories, (A)-Loads of camel's model before apply biomimicry approach; (B)- Loads of basic model after apply biomimicry approach.

5. RESULTS AND DISCUSSION

The study compares the energy consumption before and after the implementation of biomimetic design. Fig. 13, displays how much of various types of energy were used each month over the duration of a year. The x-axis shows the months from January to December, and the y-axis shows the amount of consumption used per month in kilowatt-hours per square meter (kWh/m2). This graph shows a number of changes, including:

- When it's hot in the summer months (June to September), most of energy is used to cool things down. This consumption cut in half (reduced to 50%) by imitating the camel's shape and skin properties.
- The data on heating energy consumption only pertains to the cooler months.
- The consumption of hot water, fans, and light remains consistent throughout the months shown, with slight variations.

This data is used to analyze energy efficiency or understand the seasonal impact on energy consumption for a residential model. Nevertheless, loads of the basic model after applying the biomimicry approach indicate that energy consumption peaks in the summer months primarily due to increased cooling needs. In contrast, energy consumption drops during the winter. Overall, energy use is 50% lower than in Chart A, with a 50% drop in the summer months alone.

Camels have adapted to their dry habitat in numerous important ways, which are discussed in this article. Camel fur is light-colored, so it reflects the sun's rays and helps keep the air within the animal cooler, which in turn reduces the amount of heat that reaches the skin. Insulation from the trapped air in the fur also reduces heat transfer; to apply this insulation to the outside, just paint the surfaces white beige, like a camel's coat. Camels are able to conserve water by using their nasal passages to collect moisture from their exhaled air. They also possess dispersed sweat glands for evaporative cooling. Despite having thick fur, water can still evaporate, contributing to their ability to regulate body temperature effectively. In a parallel way, some insulating materials are used, utilizing the previous technique, to regulate temperature and provide insulation. Overall, these adaptations enable camels to thrive in hot climates by maintaining a safe body temperature. The application of the biomimicry approach

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to the model (Chart B) results in a noticeable reduction in energy consumption across all categories.

Energy Consumption Categories:

- Equipment: This category shows a slight reduction in energy consumption after the biomimicry approach is the same applied.
- Fans and Light: Both categories show consistent energy consumption throughout the year, with a slight reduction in Chart B as a model after applying the biomimicry approach.
- Hot Water: There is a significant reduction in energy consumption for hot water in the summer months after applying the biomimicry approach.
- Heat: Heating shows minimal usage during the summer months and a slight reduction in the winter months in Chart B as model after applying the biomimicry approach.
- Cool: Cooling shows the most significant reduction in energy consumption after applying the biomimicry approach, especially in summer, dropping to 50%.

6. CONCLUSION

By incorporating biomimetic principles into the desert buildings in Egypt, there is considerable potential to improve energy efficiency and sustainability. Getting inspired by nature's adaptations, such as those found in the desert environment, architects and engineers could design buildings that effectively regulate temperature, utilize renewable energy, and minimize resource usage. The architects can use biomimicry to develop innovative design strategies to reduce the environmental impact of buildings and promote harmony with desert ecosystems. In desert regions, energy efficiency is critical for sustainable development and improving the quality of life. Prioritizing energy-efficient measures can address the unique challenges of living in arid areas while preserving natural resources for future generations. Water-based cooling systems, inspired by camel physiology, offer effective cooling solutions with minimal water and energy consumption. Building design can effectively manage temperatures in hot arid climates by applying principles from nature's temperature regulation systems to advanced insulation materials like aerogel and hydrogel. The use of light colors can effectively reflect high temperatures in a hot, arid environment. Using a curvature ceiling in the building compared with the flat conventional ceiling reduced the total energy consumption.

Using design principles inspired by camels, an experiment is conducted to simulate a residential model in a hot, arid climate. Specifically, the focus is on the exterior structure, color, and insulation layers resembling skin. The aim is to assess their impact on reducing temperature and energy consumption in the proposed building. A prototype of a residential unit, measuring 10 meters multiplied by 20 meters with a height of 5.20 meters, featuring a duplex height with a mezzanine floor, is situated in the El Arish region. The result reveals that implementing these design elements could lead to a remarkable reduction (0 up to 50%) in energy consumption and temperature gain. This in turn shows great potential for using insulation materials in hot environments and incorporating curved surfaces into exterior construction. The main result is that energy consumption has decreased by 50% compared to the prototype temperature conditions, which in turn achieves energy efficiency. Integrating biomimetic principles into the built environment is crucial for addressing climate change and resource scarcity, leading toward a more resilient and ecologically balanced future.

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CONFLICT OF INTEREST

Author declares no conflict of interest.

DECLARATION

The author used one of the AI technologies to improve the readability of the review.

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