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Investigating the Energy Efficiency of Biomimetic Facades based on Penguin Feathers for attaining Thermal Comfort in Interiors

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Abstract

In the past, buildings have mimicked the natural skin of animals or their natural habitat, which is a form of shelter, protection from adverse climates or has aesthetic quality. These characteristics resemble the fundamental functions of building envelopes. The biotic environment thrives without harming nature or expending excess energy. Hence, nature is a potential source of inspiration for creating energy-efficient structures.

This study will investigate if the application of Biomimicry in building facade design can regulate the interior thermal environment in an energy-efficient manner. The feathers of Gentoo Penguins that protect the bird in the Antarctic weather are emulated into a facade cladding material. The resulting design will be tested via computer simulations, in this case in Design Builder, for thermal comfort, fabric performance and energy efficiency. A comparison between a conventional facade system and the bio-inspired facade is made to confirm which system is more efficient in terms of thermal performance and energy use.

Keywords:

Biomimetic facades, energy-efficiency, penguin feathers, thermal envelopes, computer simulations

1.0 Introduction

Natural organisms are physiologically capable of surviving in their ecosystems by virtue of their physical appearance or behaviours. The skin of each organism is diverse and serves various functions depending on the environment in which it thrives [Pawlyn, 2011]. For example, the hard scales of a Pangolin in Africa protect it from its predators, where as a hard exoskeleton, can also serve to avoid water loss in a desert Namib beetle. In the colder regions, thick fur of a snow leopard, and layers of feathers on the Arctic Penguin serve insulation purposes. Both the building skin and human skin are subjected to similar environmental conditions [BioSkin, 2012]. Hence, it is possible to compare

shells of nature to building envelopes. The façade directly involves in gain and loss of heat and energy [BioSkin, 2012] from the building. The fabric of the building has the potential to alter the temperatures of the interior environment by storing or releasing heat into the building. This study investigates Bio-inspired façade materials that can cause adequate thermal conditioning for a temperate climate. This paper will interest architects, designers, biologists and engineers who seek to address the global energy issue through inter-disciplinary innovations.

2.0 Proposed Biomimetic Façade

Appropriate design of building insulation can facilitate heat retention during winters and prevent ingress of heat during summers. One of the finest examples of insulators is the feathers of the Gentoo Penguins (*Pygoscelis papua*) from Antarctica. The primary means of insulation in penguins is the tuft-like after feathers. Studies on the penguin's coats (feather and skin assembly) proved its thermal resistance to be $0.74 \text{ m}^2\text{KW}^{-1}$ [Drent and Stonehouse, 1971]. It was concluded that convection does not occur in the coat of the penguin and radiative heat loss is minimised [Dawson et al, 1999] thus enabling the bird to survive in the Antarctic weather.

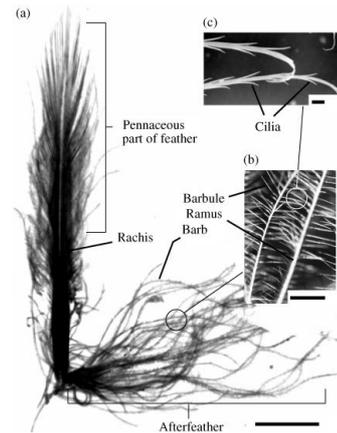


Figure1: Components of the penguin feather.
Source: Dawson et al

3.0 Creating a Thermal Model based on the penguin feathers

Dawson and Vincent [1999], in their article suggested a thermal model based on the structure of the penguin feather (see figure1) by making a few assumptions:

- (a) The outer part of the feather is a wind and waterproof layer while main insulation is provided by the after-feathers.
- (b) The feather is composed of smaller barbules which interact to form horizontal layers within the insulated air space.
- (c) The barbs are extended to their full length; barbules from one barb interact with its nearest six neighbours (feathers arranged in an orderly fashion).

4.0 Building with proposed Biomimetic facade

An office building in Sheffield with a double-wall on the north-west face is chosen for this study. The structure of the penguin feather and its characteristics that offer thermal insulation were best mimicked using Design Builder software to create a façade cladding material. The U value of the material is as low as $0.08\text{W/m}^2\text{K}$.

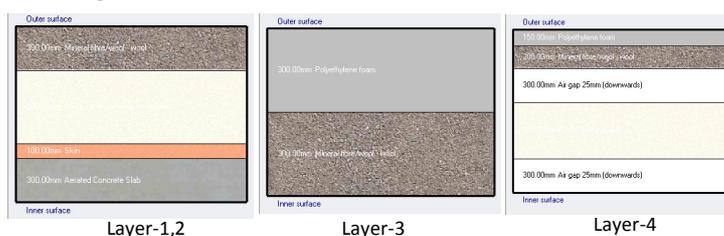


Figure2: Building layers Alternating Layers

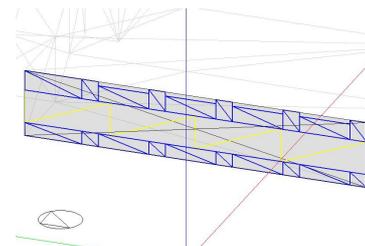


Figure3: Application of materials on the model

Table 1: Layers of Penguin feathers Vs Building Material layers in Design Builder

LAYERS (From innermost)	PENGUIN FEATHER		BUILDING MODEL	
	Layer	Function	Layer	Function
1.	Skin	Thermoregulation base	a) Aerated Concrete Block	Base
			b) Skin	Base
2.	After-feathers	Main Insulation	a) Foam polyurethane-freon filled	Insulation
			b) Mineral Wool	Insulation to interact with next layer
3.	Rachis	Main stalk that supports individual insulation barbules	a) Polyurethane foam	Insulation
			b) Mineral Fibre wool	Insulation
4.	Barbules and outer Pennaceous layers	Barbules-horizontal layers that subdivide air space beneath insulation Pennaceous-Waterproof and Air proof layer.	a) Air gap	Insulation that breaks air spaces
			b) Foam Polyurethane	
			c) Air gap	Air proof
			d) Mineral Wool	
			e) Polyethelene Foam	

5.0 Building Simulation

The building was simulated without the double wall but the biomimetic material on the main façade. The data set for the simulation is a naturally ventilated with an open-office schedule of operation, biomass as fuel for heating, 40% operable glazing, all computers and equipment turned on. The walls are cast concrete with internal insulation and the glazing is double-glazing. The model did not consider installation of the material, just the properties of its layers. The results generated from simulation were as follows:

5.1 Temperature and Comfort

Winter conditions for individual office spaces indicate least operative temperatures of 17°C during a typical winter week (15th-25th December). The maximum temperature in winter is 23.5°C, which is considered comfortable. The zone sensible heating for an individual office zone is 144.61kW. During summers, the office zone reaches a maximum operative temperature of 28.8°C which is not a comfortable condition for summer.

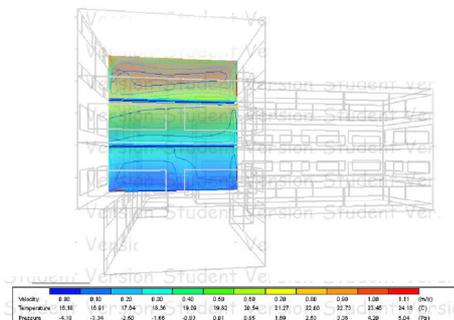


Figure 4: CFD simulation of temperature distribution on 15th July.

Source: Design Builder

5.2 Energy-efficiency (System loads)

Suitable heating is supplemented during winters. For adequate zone heating in January, the building requires 48,762.9kWh of energy for heating (see figure.5). The system is turned off during summer conditions.

5.3 Fabric and Ventilation

Through the biomimetic material, very minimum heat loss occurs from the building fabric in winter and summer and the building is more airtight (see figure.6).

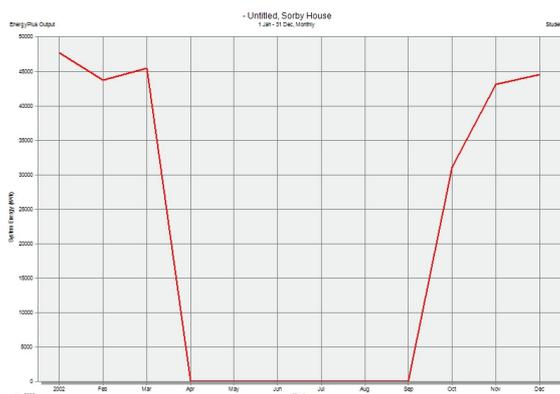


Figure 5: System loads of the building
Source: Design Builder



Figure 6: Fabric performance of the building.
Source: Design Builder

According to the anatomy of the penguins, maximum insulation is achieved due to the closely packed arrangement of the feathers on the body of the penguin. To test, if ‘arrangement’ affected the performance of the insulation of the building, the simulation was tested by applying the material layers as wall material and not as cladding material with alternate layers. This change affected the comfort conditions and heating loads. But the performance of the building fabric was unaffected by material application. The highest hourly temperature reached in winter for the office zone is lower than original; 22.3°C. The heating loads in the office zone is 150kW to maintain comfort, which is also higher than the original case with surface cladding.

6.0 Comparison of results

After running simulations with three cases and three sub-cases, the following results were achieved:

Table 2: Comparison of simulated results of double wall façade and biomimetic façade

Parameters	Building with Double wall façade		Building with Biomimetic façade cladding material	
	WINTER	SUMMER	WINTER	SUMMER
Monthly maximum operative temperatures	13.36°C	28.49°C	18.3°C	30.1°C

Hourly max. operative temperatures in office zone	21.7°C	24.73°C	23.5°C	28.8°C
Hourly heating load in typical winter week	253.23kW	-	144.6kW	-
Monthly heating loads	25,282.32 kWh	-	48,762.9 kWh	-
Max. heat losses from walls	5461.32 kWh	3586.5 kWh	1340.93 kWh	125.34 kWh

7.0 Analysis

In terms of comfort during winters, the biomimetic façade material is able to produce more comfortable conditions than the double wall system. This is because of the insulation quality of the façade material that retains the heat in the interiors. During summers, the double wall system is able to deliver more comfortable conditions than the building with biomimetic façade material. This is because the double wall can delay the ingress of the heat in the interiors due to the air gap in the façade. Hence, this system is more efficient than the building with the proposed biomimetic cladding material. Without either the double wall system or the biomimetic cladding material, the building experiences very high summer temperature and moderate winter temperature.

It can be seen that in case of the double wall façade, the individual zone sensible heating of the office zone is higher than the rest of the cases. This is mainly because the office zone faces the double wall façade. It experiences more losses through ventilation and glazing. Hence heating the space requires more energy than the rest of the building.

Being a passive mechanism the double wall system has to ability to cause heating without expenditure of energy. The double wall facade system is twice as energy-efficient as the biomimetic façade cladding material.

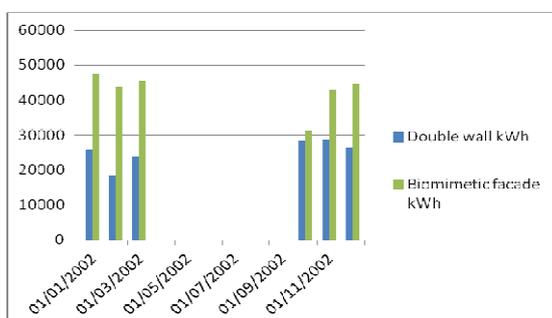


Fig7- Comparing energy-efficiency (Energy required for heating)

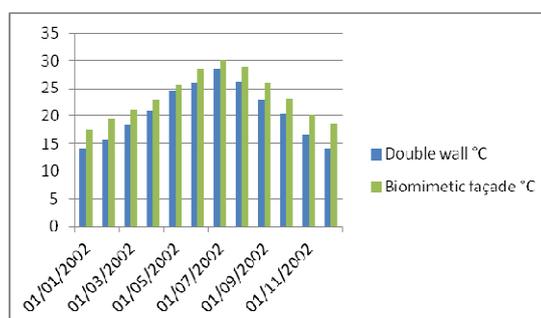


Fig.8- Comparing monthly operative temperatures

