American Journal of Materials Engineering and Technology, 2013, Vol. 1, No. 2, 22-29
Available online at http://pubs.sciepub.com/materials/1/2/2

DOI:10.12691/materials-1-2-2

Designing a Mobile Facade Using Bionic Approach

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Received December 14, 2012; Revised May 09, 2013; Accepted May 10, 2013

Abstract The laws of nature are reasonable valid ones that have been tested throughout the years and proved effective; the survival of living beings is proof to the claim. Natural creations are great examples to be used as patterns since they respond in the best possible way to their natural needs. Products that are most compatible with living environments can be produced by using the creative points in each living entity and its responses to natural needs and habitats as patterns. Nature and living things are all based on similar principles in terms of form and structure. Aesthetics and proper form, being optimized, consuming the least energy and being most productive, and etc are all aspects which architects and designers try to take into consideration and implement within their designs. Therefore, study and research on such natural samples and detecting the systematic thought hidden within them, and also implementing them in designs can result in buildings responding in the best possible way to certain environmental needs, parallel with their primary natural pattern. What is studied throughout this research is the coverage of inhabitant birds within the design site, identifying the pattern of their feather arrangement, and finally the effect of the pattern in the level of energy consumption during summer and winter. The results of the present study lead the designer towards a mobile surface with the aptitude to reduce energy consumption in winter and maximizing shade during summer throughout the project site.

Keywords: *biomimetic, nature, bird coverage mechanism, mobile façade*

1. Introduction

Man has always been and is living with nature while trying to achieve a better state of life. Throughout history, he has always attempted to learn from Mother Nature and gain new experiences which facilitate a better and more efficient state of living. By observing the nature, humans have gained the knowledge they use in various sciences for efficiency and effectiveness. That is since nature has always had the best answers to the problems upfront, and nature-based structures will certainly have the same advantage. Basically, the bond between natural systems and manmade structures is important in the aspect that the dynamic within the prior leads the latter towards optimum and effective forms, the very fact that can be a proper pattern for man to design artificial structures. Meanwhile, architecture is able to utilize information from nature to construct structures with humans in them, so that buildings with the most comfort and compatibility possible are designed and built. By using a natural sample as a pattern and analyzing it, the present study aims at reaching solutions to implement in building designs and presenting one that is synchronized with nature to enhance levels of comfort for users within such spaces.

2. Bionics, the Science of Seeking Excellence in Nature and Imitating it

Mindful simulation of nature is a method of survival for mankind. The way to reach a solid future and the science whose focus is to make use of nature is called bionics. The term “bionics”, which explains the relation between nature and product design, is the process of innovative designing and engineering based on the systems present in nature. Biomimetic can also be mentioned alongside bionics, which refers to mimicking nature and mainly focuses on using the common mechanisms in nature to form structures [1]. This science relies on learning from nature to reach a solid stability and is based on ecological literacy. Ecological literacy means to understand the principles of organizing the natural ecological systems, and using them to create stable manmade constructions. Meanwhile seeking excellence in nature, we can take a look at natural ideas from various perspectives; for instance tips can be extracted from natural forms of creatures, their dominant geometry, the proportions and arithmetic used in them, their evolutionary processes, ecosystems, etc to combine with human facilities and knowledge in order to accomplish new results and products with high efficiency. While pursuing such an end, after finding the key and practical points of a natural structure - a bird -, the present study has embarked on implementing the structure within the architectural design of a mobile façade.

3. Introducing the Natural Pattern Structure

The pattern structure is a bird called Columba Livia. The bird’s being native and present in both summer and winter around the site of study, Tehran, is the reason behind the selection. The continual presence of the bird reflects its ability to adapt and conform to the conditions of its habitat. The biological information of this bird is given in Table 1.

Table 1. Overall information of the bird [2]

Latin Name	Columba livia ('dove' or 'bird of leaden or blue-grey colour')
Common Names	Pigeon, dove, blue rock pigeon, rock dove, wild rock pigeon, rock pigeon, feral pigeon
Bird Order	Columbiformes
Family	Columbidae (includes 315 different species)
Origin	Europe, North Africa and Asia.
Habitat	The wild pigeon is found in coastal areas and the feral pigeon is found almost exclusively in areas of human habitation.
Body Length	32-37cm
Wingspan	64-72cm
Body Color	Dark bluish-grey head, neck and chest with glossy greenish and reddish-purple iridescence around the neck and wing feathers
Eye Color	Orange or red iris with pale inner ring (adult) or brown or greyish brown (juveniles)
Beak color	Black bill with off-white cere

The pattern structure has been studied on three scales. The first one is "macro scale" which includes information from studying the body and leads to general principles of its co-existence in the habitat. The second one is "middle scale" which presents the patterns of mobilization mechanisms, and the third one is "micro scale" which studies the microstructure of feathers.

3.1. Studying the Natural Pattern Structure in Macro Scale

The solutions birds seek in cold weather can vary but include gathering around and lodging. For instance, lodging for a kind of dove augments its coverage up to %400, increasing its resistance in cold up to %56 [3]. The physiological role of feathers is to create an insulator which is considered to be the guarding mechanism of metabolism heat. In birds the insulator enhances with the increase in feather volume. This makes birds more resistance in very low temperatures [4]. The condition happens by trapping air in the dead pores using feather arrangements in skin. Feathers of birds are not arranged on their skin coincidentally, but on a line called Pterylae. The spaces free of feathers on a bird's body are called "Apteria". The arrangement of the feathered or un-feathered spaces on a bird's body is to create compatibility after the final decrease in its weight, have better compatibility between body movement and feathers, and most importantly, help the body temperature setting by losing heat in un-feathered spaces [5,6,7].

3.2. Studying the Natural Pattern Structure in Middle Scale

The skeleton of a wing is similar to that of a human hand, a four-bar linkage mechanism. A four-bar linkage mechanism is a series of organs attached by joints. In general, joints are structural elements and where movement occurs. In the four-bar linkage mechanism of human hand, shoulders are the fixed arms, arms are the mobile arms, forearms are the attaching arms, and palms are the follower arms. In birds, arms are shorter than forearms and finger bones are continual. Between the shoulders and wrists there is a long tendon where the Primary and secondary remigs are attached to the hand and forearm areas on the wings, as a fan.

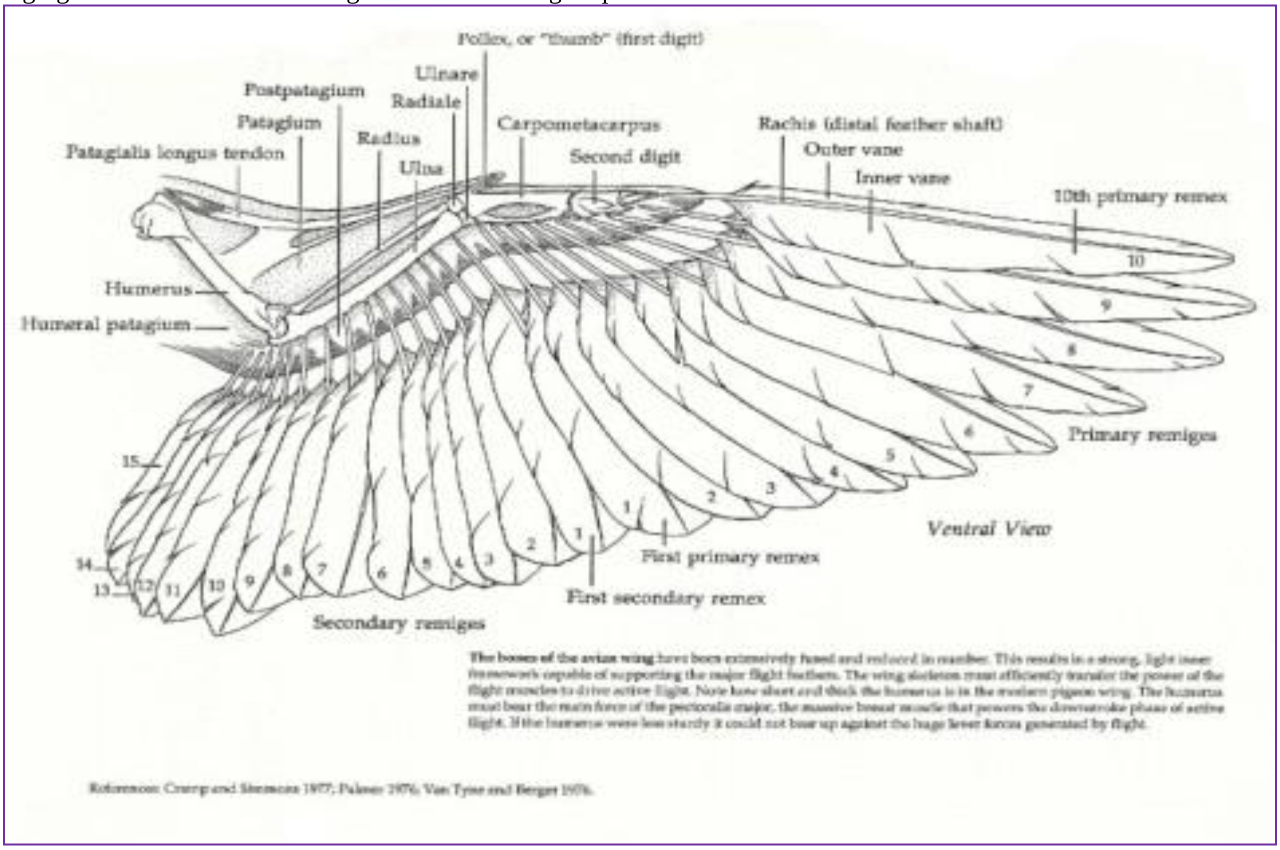

Figure 1. behind view of a bird

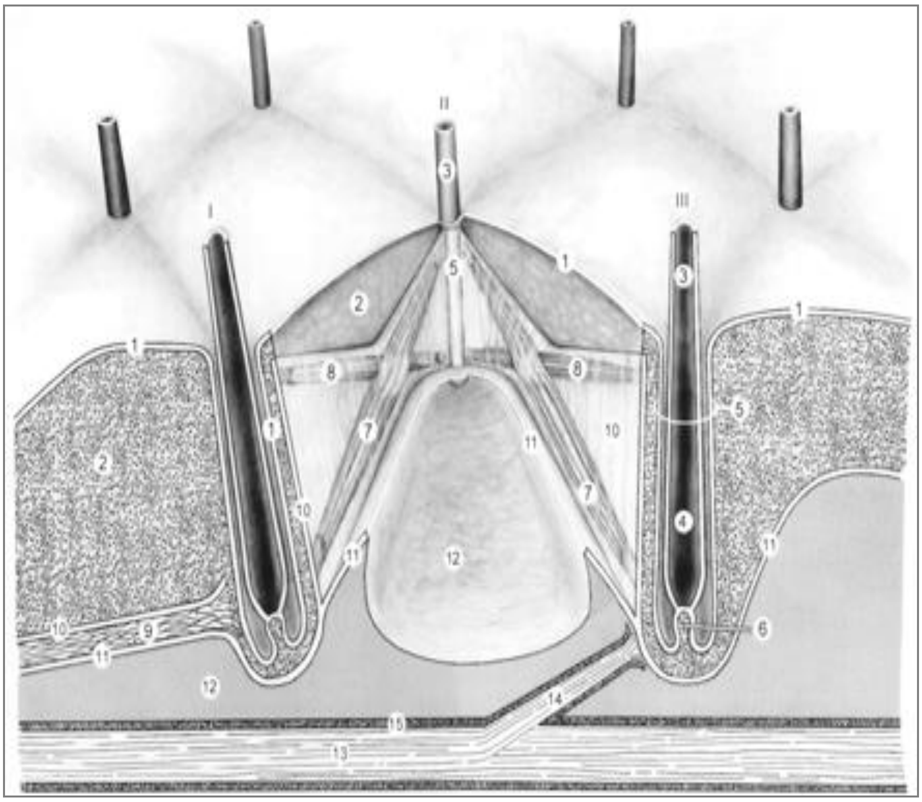

Figure 2. section of bird skin

Another point in this scale is the way feathers move on skin. The stratum is the first layer on top of a bird's skin. Figure 2 show the vertical segment of where feathers join skin on Meleagris gallopavo in the middle area of the neck. The process of feathers' getting puffy and lying on the surface of body allows the bird to access layers below for cleansing in addition to trapping air within feather layers. The Figure below shows the contraction and tensional muscles causing the feather movements.

If we simplify the diagram of this movement, we get the two-dimensional view that is shown in Figure 3. State A shows that the recumbent feathers rise up by muscle contractions. In state B, the risen feathers are tensed back to the recumbent position by the resilient quality of elastic layer, and in state C, feathers are stabilized by the contraction muscles against the outer raising powers [8].

As shown in this simple figure, feather movements on skin are caused by a four-bar linkages mechanism on skin which can be perfectly imitated in manmade structures.

3.3. Studying the Pattern Structure in Micro Scale

The structure of feathers consists of a central shaft and two neighboring blades, both of which have their own name and practice. The microscopic images clearly demonstrate the overlapping of these two edges [9]. The microscopic structure of the vanes of feathers was first observed by Robert Hooke (1665), who found that adjacent barbs of goose quills are linked by two series of barbules which diverge from the proximal and distal margins of the barbs. The barbules on the distal surface of each barb are provided with hooks on their ventral surface which interlock with grooves on the proximal barbules of the next distal barb (Figure 4).

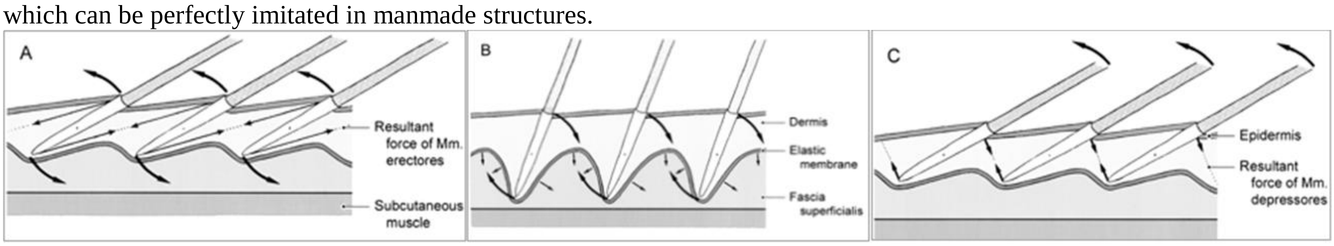

Figure 3. the two-dimensional model of feather movements, scalp is placed on the right and tail on the left

This arrangement produces a light structure which, because of the large number of points of attachment, is relatively strong and, if broken, may be easily mended by the bird drawing the vane through its bill. The asymmetry in the flight feathers is also well known; in many flight feathers, the shaft is situated approximately at the quarter chord position, close to the front of the blade, where the aerodynamic forces would be centered if the feather was acting as an independent aerofoil. The shaft will therefore be subjected to bending forces alone and will not be twisted [10]. On the other hand, as shown in Figure 5, the barbules on one side of the barb are located higher than the other side; therefore, the neighboring barbules can be latched together and air is trapped within the empty spaces, providing an isolation layer for the bird.

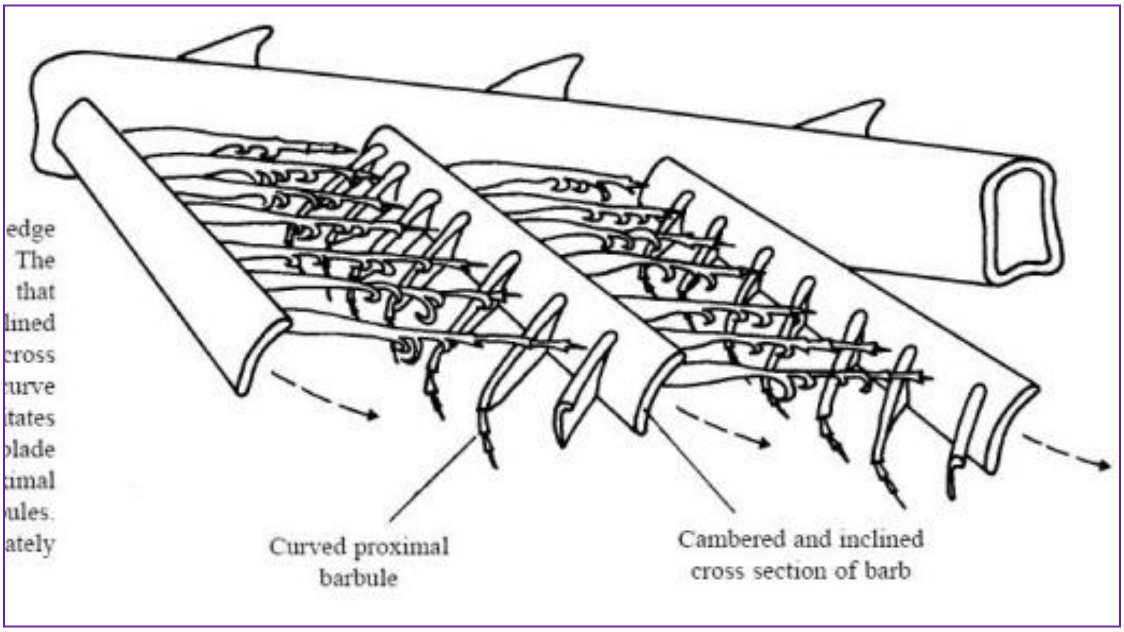

Figure 4. The structure of the trailing edge vane of a pigeon primary feather. The barbs are inclined from the vertical and cambered in cross section and the proximal barbules curve near their tip. This structure facilitates distal and ventral movement of the blade (arrows) and helps prevent proximal movement and detachment of the barbules. Distance between barbs is approximately 0.5mm

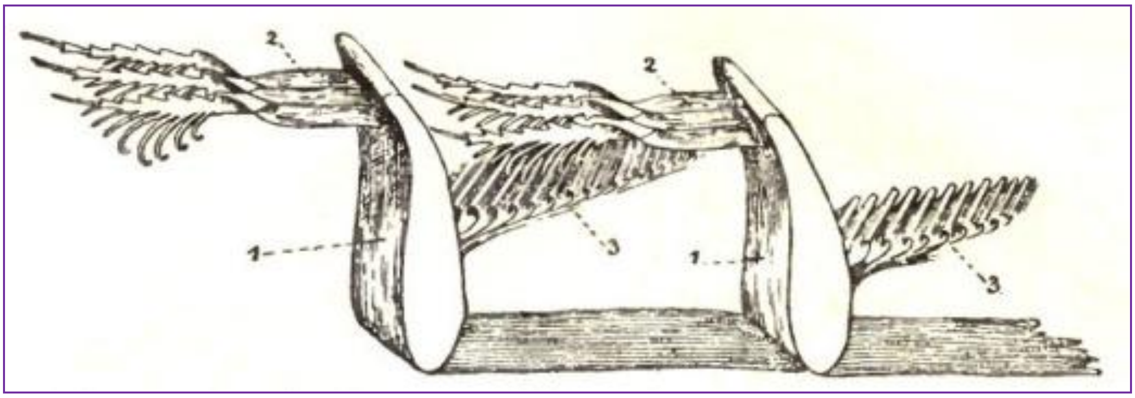

Figure 5. The descriptive diagram (1) of barb segments (2, 3) and barbules involved in one another

4. The Information from Studying the Natural Pattern

Studying in nature can provide architects with key points on utilizing in architectural design. In the present study, choosing nature as a pattern, and more accurately, imitating birds' coverage and structure has led to solutions which contain the potential to be used in stable architectural structures. In this study, the points are used to design an urban fa çade in Tehran since many buildings around the city are constructed with a fixed fa çade, neglecting the standard conditions of peace and comfort. Using the information from studies of nature will lead to a better quality of life and living conditions. The fa çade designed by such solutions will enjoy the following primary benefits:

1. The ability to change shading on the building during summer by utilizing rotating elements,

2. The ability to decrease wasting heat in winter to trap a layer of air within the elements of the fa çade,

And also secondary benefits such as:

3. The mobile nature of fa çade elements to reduce costs,

4. The competence to be attached to old and present building for lightness,

5. Creating coordination between the present facades throughout the city by using this type of fa çade.

5. Implementing the Imitated Rules of Nature in Architectural Bodies

Based on the conducted studies and gained information, three ideas were developed for structuring the mobile fa çade. Then, the effects of their existence or nonexistence were studies and contrasted in the northern, southern, eastern, and western sides of the building.

5.1. First Idea

Based on the studies of Macro Scale, it was concluded that trapping air between the feathers in birds can be a factor in enhancing the insulator, which makes it capable of preventing waste of energy up to %56. Moreover, in the Micro Scale studies of the feathers, it was clear that the very trapping of air is feasible through the micro scale with special kinds of overlapping of barbs and barbules (Figure 5). Thus, the following fa çade was designed:

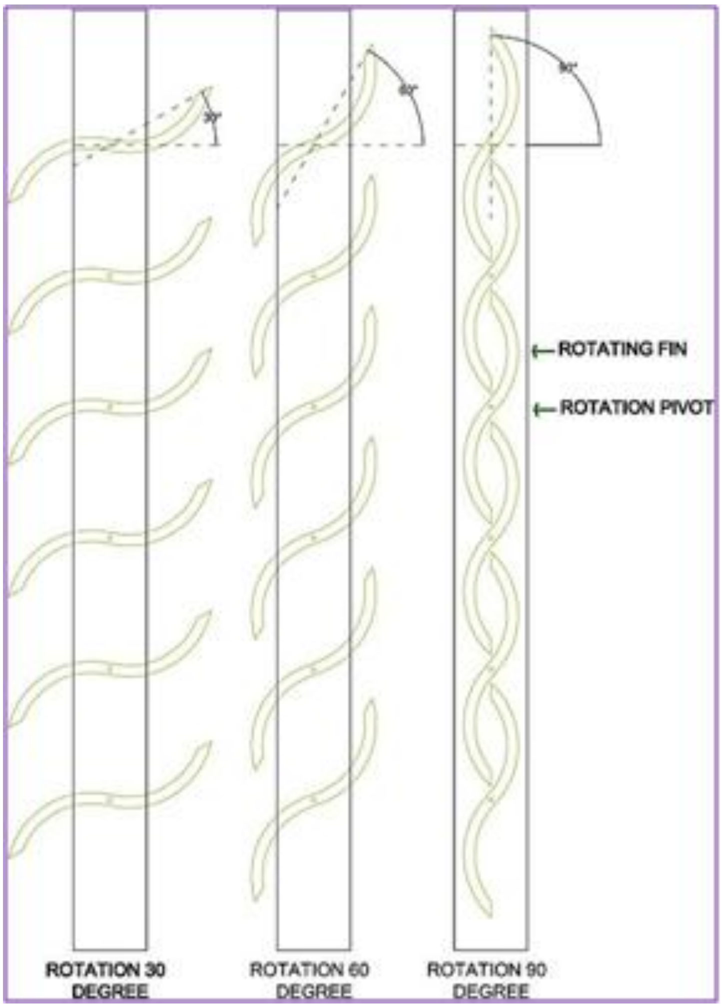

Figure 6. Idea No. 1

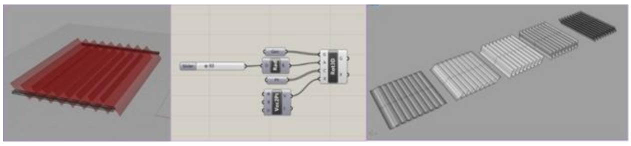

Figure 7. Modeling the movement phases by Grasshopper software and presenting the various movement phases of this idea

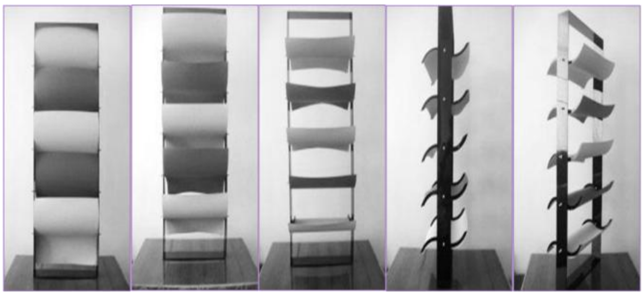

Figure 8. The model of movement phases of idea No. 1

Therefore, the curviness of elements causes a trapping of air between the two façade elements, acting as an insulator.

5.2. Second Idea

In the middle scale studies based on Figure 2 and Figure 3, it was stated that a mobilizing pattern of façade elements can be developed by simplifying the movements of feathers. In fact, the mechanism is that of a pair of scissors based on which a façade similar to the following figure can be design. Such a façade can be controlled both manually and intelligently. Furthermore, it can be designed as a partial or total façade. It should be said that such a façade will have the ability to be implemented vertically, horizontally, or both ways. This idea requires one of the supports to be movable.

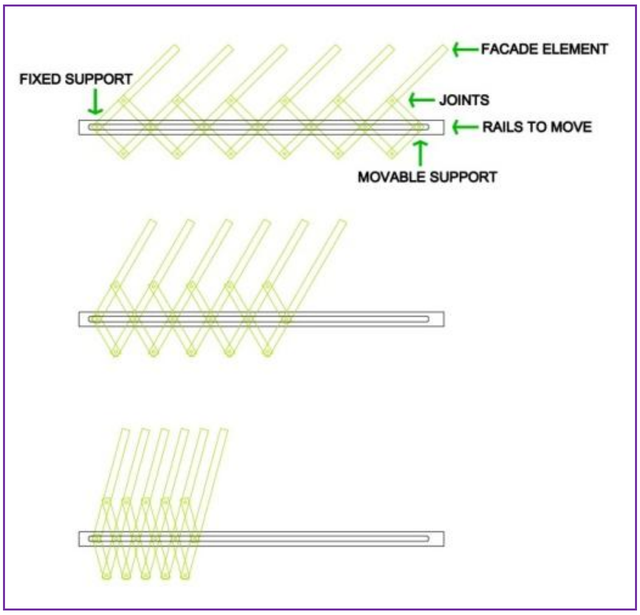

Figure 9. Model of movement phases of idea No. 2

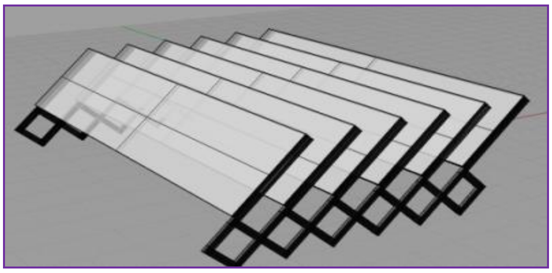

Figure 10. perspective of the idea No. 2

Figure 11. model of movement phases of idea No. 2

5.3. Third Idea

This one is a combination of the first and second ideas. In this one, the air trapping occurs similar to the first idea, where the movement mechanism is different. The movement mechanism of this idea has been designed by simplifying the second idea. Thus, the movable support is no longer valid.

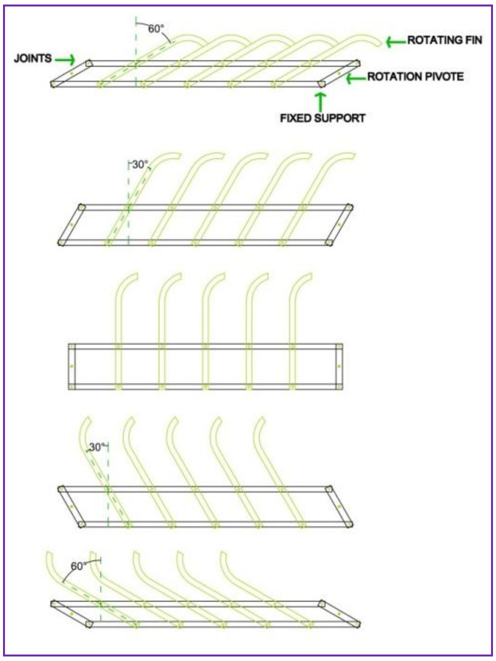

Figure 12. the model of movement phases of idea no. 3

Air trapping still occurs through curvy elements and insulator is provided.

6. Temperature Analysis

The first idea among the presented one underwent temperature analysis. What this analysis was after was the specifications of the optimum shade to develop the insulator in winter and proper shading in summer.

To examine the effectiveness of shades and their forms on the temperature of the building, 12 various models were simulated on three sides (southern, eastern, and western). Therefore, 36 different models were simulated in the Ecotect software 2012, and transferred to Energy Plus 7.0 for necessary calculations. The climatic information of Tehran based on the weather information of Mehrabad station was given in Energy Plus 7.0. The aforementioned models were divided into four groups. This classification is based on the angle the shades make with the horizon, being respectively 0, 90, 45, and 135 (Figure 13).

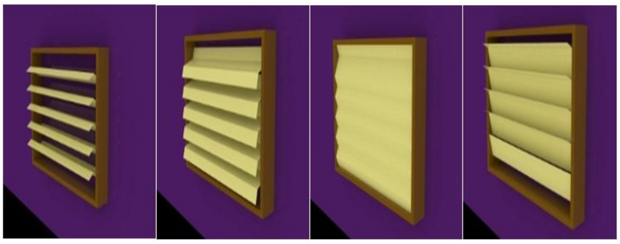

Figure13. Vanes, angles from left to right 0, 90, 45, and 135

The heating and cooling load of the building was compared and contrasted based on the following graphs.

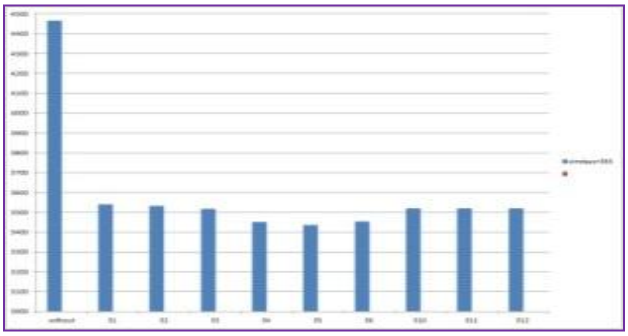

Figure14. Cold load on the eastern side

Figure15. Heat load on the eastern side

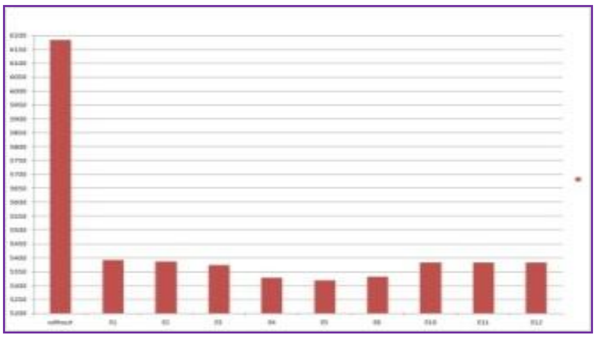

Figure16. Temperature load on the eastern side

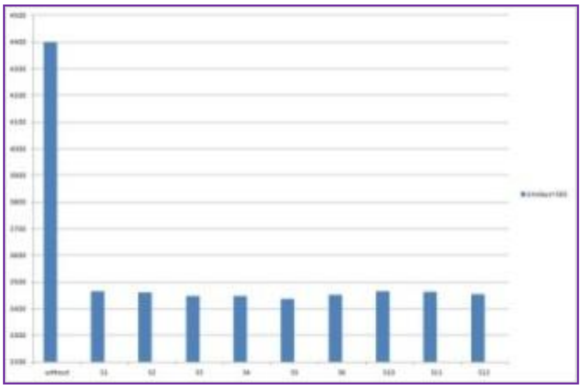

Figure17. Cold load on the southern side

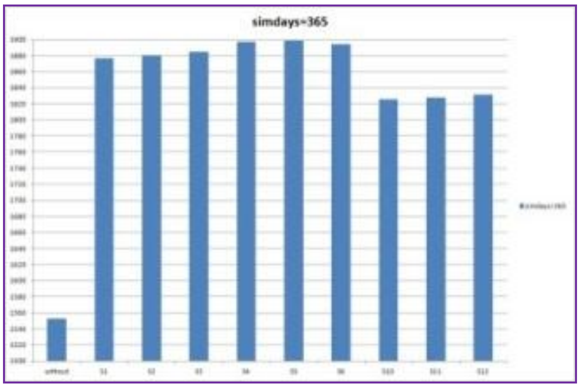

Figure 18. Heat load on the southern side

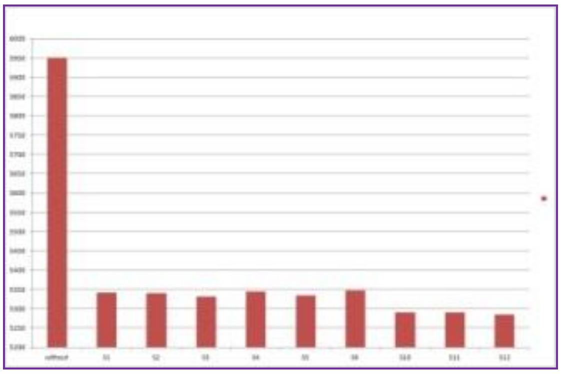

Figure 19. Temperature load on the southern side

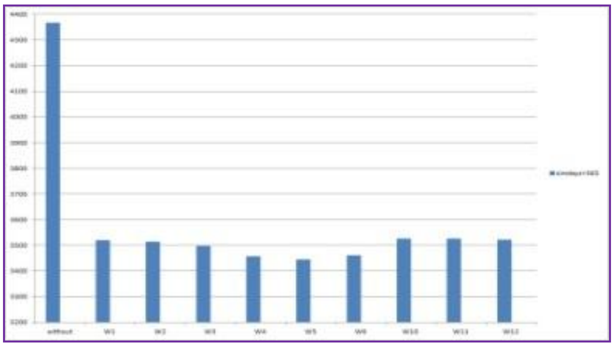

Figure 20. Temperature load on the western side

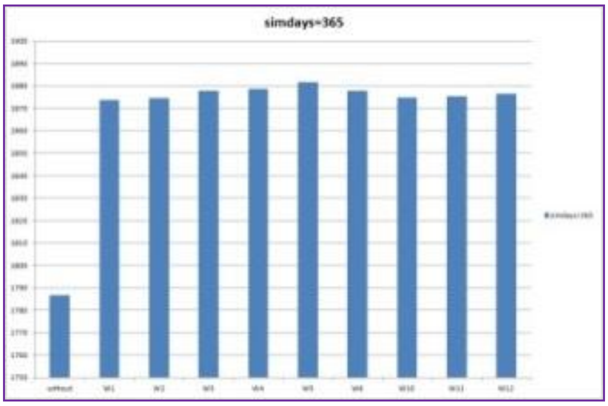

Figure 21. Heat load on the western side

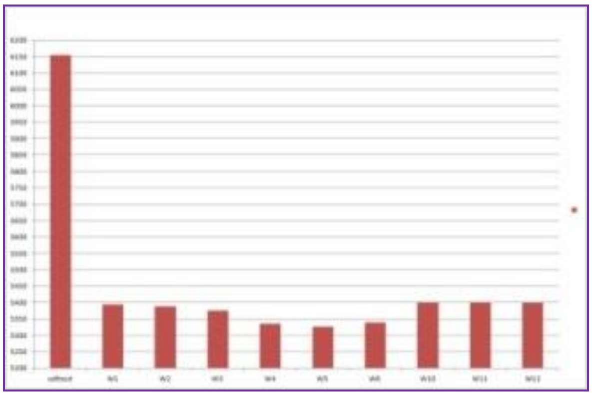

Figure 22. Cold load on the western side

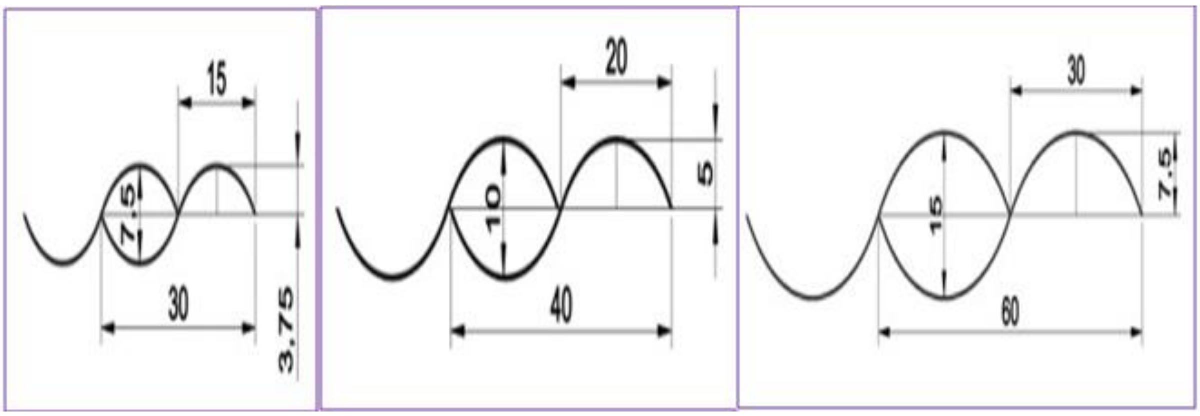

Figure 23. Three proposed models for temperature analysis

7. Conclusion

As expected, the graphs of heat on all sides show that using shades generally increases the heat load on the building. The reason is that shades prevent the receipt of sunlight during cold days and increases the heat load of the building. Based on the graphs of cold on all sides, using shades remarkably decreases the cold load. The graphs of total heat and cold were compared and contrasted on all sides to study the effectiveness of shades on temperature load of different sides of the building. The results indicate that shades decrease the temperature load of the building. Using the model with 90 angle which blocks the direct and scattered sunlight entirely, highly increases the heat load on the building. That is why designing a shade that is transformable into a 90 degree angle during cold nights (preventing the heat transfer at night) in long cold seasons and back to 0 to receive direct sunlight is the most optimum use of a shade. It must also be mentioned that designing these shades horizontally during hot seasons when sunlight is vertical can prevent the heat, while facilitating receipt of direct and scattered sunlight in cold seasons when sunlight is slanted. Comparing the graphs of temperature load on all sides introduces the optimum form for each side. Among the models of 0, 45, and 135 degree angles, angles 45, 45, and 135 were respectively the most appropriate one for the western, eastern, and southern side.

The models above were each simulated with 3, 5, and 7 vanes, where in each element of model 1, 2, and 3 the depth of trapped air was respectively 3.75, 5, and 7.5 cm, and when the elements facing each other 7.5, 10, and 15 cm (Figure 23).

According to the graph, the shade of the second model (5 vanes), on the eastern/western side and the shade of the first model (7 vanes) on the southern side the shade have the optimum states.

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