

Increasing efficiency with biomimetic approach in thermoregulative building envelope strategies supporting internal thermal comfort

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Abstract

There has been a plea for sustainable use of resources since the twentieth century. Buildings are known to consume forty percent of the world's resources. Resources such as gas, oil, coal and electrical energy used in heating, cooling and ventilation of buildings are limited, as well as causing air pollution and climate change. For this reason, the energy resources used in the buildings should be used effectively, considering environmental concerns. The aim of this study is to describe the shift in efficient use of energy in buildings using a biomimetic approach in thermoregulative building envelope strategies that support internal thermal comfort. In this study, passive systems integrated into buildings which use solar energy, one of the renewable energy sources for heating, cooling and ventilation purposes have been examined. The methods followed by nature in using solar energy are discussed with the biomimetic approach and suggestions have been made to support the increase of energy efficiency by applying the obtained teachings to passive building envelopes.

Keywords: biomimetics; building envelope; kinetic building envelope; passive strategies; Thermal comfort

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1. Introduction

Forty (40%) of the energy in the world is used in buildings. Eighty (80%) of the energy in buildings is used for heating and hot water needs. In today's conditions, while the need for heating is provided by gas, oil and coal, the need for cooling is provided by electricity and the demand for electricity consumption will increase over time. Even today, the share of buildings in CO₂ emissions is 30% and this rate will increase over time. Existing warming and cooling methods cause air pollution, consumption of limited resources and climate change along with global warming, while also damaging the economy. Failure to meet and distribute the demand for energy for thermal needs at the same rate are other problems in the management of energy resources[1-3]. When the studies carried out in the last 40 years are examined, it is seen that engineering and energy sciences and environmental sciences are the fields that have an active role in providing comfort in living spaces. Energy should be used economically in order to reduce the damages that occur while providing thermal comfort and to make the best use of the available resources. In order to develop effective temperature management strategies in buildings, multidisciplinary studies of relevant scientific fields are required. In this context, building technologies and engineering applications that play an active role in the interaction of buildings with the environment should come together[4]. In this study, building envelope technologies that support energy efficiency with passive strategies in zero-energy buildings and their contribution to energy efficiency have been examined and the benefits of design using nature-inspired methods in increasing energy efficiency are discussed.

2. Methodology

This research is a descriptive research that describes an efficient way of improving energy use in buildings by using building envelope technologies. The research discusses the suggested methods and makes references to existing literature that are related to the topic under study. Suggestions are made and the composition of the building technologies are described in detail as well. The research gives some options that are available and describes the composition of those options as well as how they work. The research constantly makes references to existing literature to establish validity of the suggestions that are made in this study.

3. Improving energy efficiency

3.1 Passive Building Envelope Technologies

While providing thermal comfort for people living in buildings, it is also necessary to minimize environmental impacts in order to reduce carbon emissions and prevent climate change. In the literature, while the cost of today's technologies and the energy consumption required for the management of systems are among the striking points, environmental impacts have also started to become important[5]. This is causally related to the reduction of energy consumption. The reduction of energy consumption in buildings can be achieved by firstly reducing the energy demand in buildings by self-sufficiency and then providing the necessary energy with renewable energy sources. That is, buildings must be built in such a way that require lesser amount of energy consumption and thereafter the introduction of renewable energy resources would be introduced to further reduce energy consumption. Such buildings, based on the principle of managing energy in this way, are defined as Zero Energy Building (ZEB)[6]. The buildings in the ZEB concept, aiming to minimize energy consumption, prioritize passive building envelope strategies that aim to obtain energy without requiring extra performance. This includes insulation, natural ventilation, DSF(Double Skin Façades), shading, green area use, thermal loading(Phase Change Material-PCM), free cooling, roof coatings, evaporative cooling,

roof ponds, which provide thermal energy management in harmony with nature and in buildings, Passive building envelope strategies applicable to roofs and walls[7].

3.1.1 Thermal insulation improvements

Thermal insulation improvements have been one of the main components of reducing energy consumption with the advancement of building envelope technology. Heat loss due to air leakage in building envelopes can be up to 40% of the total heat loss[7, 8]. To prevent this, the traditional insulation materials used in buildings are mineral wool, expanded polystyrene (Expanded Polystyrene-EPS), extruded polystyrene (Extruded Polystyrene-XPS), polyurethane (Polyurethane-PU), cellulose and cork. Innovative materials used in insulation are Vacuum Insulation Panels (VIP), Gas-Filled Panels-GFP, aerogels, Vacuum Insulation Materials (VIM), Nano Insulation Materials-NIM) and dynamic Insulation Materials(DIM)[9].

3.1.2 Natural ventilation

Natural ventilation, which is another way to provide thermal comfort, is to meet the need for cooling without consuming energy thanks to solar radiation and the pushing force of the wind in hot seasons[7, 10]. The air corridors in the buildings defined as wind catchers, solar chimneys and atriums are among the structures used with natural ventilation. The geometry, number and location of the atriums are important in terms of the efficiency of the air currents to be created in the building[7, 11].

3.1.3 Double skin facades

Double Skin Façades are a general group name given to the wall model based on the principle of airflow flowing through the space between two parallel walls, and it is diversified according to the structure, geometry, ventilation mechanism in the space and air flow diagrams. DSF, which accumulates solar heat, consists of the combination of an outer wall made of dark and high-density material and a transparent wall 10 cm in front of this wall. The wall behind loads the heat while the transparent wall passes the sun's rays. DSF walls are used to warm up in winter and cool in summer. Even though the sunrays that cannot be absorbed by the wall reflect back to the glass, some of them cannot come out and remain inside. These rays heat the air in the space between the two walls. The heated air is transferred inside through the vents on the upper part of the wall and the indoor environment is heated. In summer, cool air is taken from the outside through the culverts opened under the wall. Cool air rises inside, warming up and is thrown out from the vents on the wall[12]. DSF provides sixteen percent (16%) energy savings[13]. Passive shading systems reduce the heat load and cooling need of the building by directing the sun rays specifically to the building, while also providing natural lighting within the building[7, 14].

3.1.4 The use of Green areas

The use of green areas, another passive strategy for energy conservation, is preferred on the facade, roof and balcony sections of the building. The use of foliage prevents moisture and sudden temperature fluctuations. Especially in old buildings with poor insulation, the extra layer created with plants improves the insulation. Since the sun's rays are steep, the use of green spaces provides maximum benefit in summer. The use of greenery, which meets the cooling needs of the building in summer thanks to

evaporation, sweating and shading, contributes to thermal energy management in winter with its contribution to insulation[15, 16].

3.2 Heat management

Heat management in buildings can also be achieved by thermal loading, which can be defined as the absorption, storage and release of heat. This use of heat can be achieved with Phase Change Material (PCM)[7, 17-19]. Building envelopes with high thermal load properties reduce and delay the environmental temperature and transmit it to the building. This is called "thermal inertia"[20]. With this feature, thermal load allows the energy to be used the next day by lowering the peak load point. Since it balances the energy demand, it also provides energy conservation[21]. Free cooling, in which natural ventilation is used for cooling, is a strategy that uses the outside air as a heat sink with ventilation, which is used when indoor temperature is higher than outdoor air temperature. For this, the outdoor temperature should also be in the comfortable temperature range[7].






Among passive strategies, reflective roof coverings for cooling purposes, such as green roofs and roof ponds, are used to prevent heating of the building. For this purpose, "albedo" materials are used, which means the degree of whiteness of a material and can reflect light without absorbing it. Roofs covered in the form of coatings, membranes or tiles can reduce the energy need up to 57% while providing indoor thermal comfort by preventing overheating of the building in summer[7]. Evaporative cooling, which is based on the principle of evaporating water in an area, is cooling by transferring the heat load to the outside air through moisture. This method is used as a passive cooling strategy in summer and in arid climates. It provides a wide range of use due to its high efficiency, low cost, ease of maintenance and attractive payback period[7]. In roof ponds, another passive strategy, cooling is achieved by combining indirect evaporative cooling method and radiative cooling method in summer, while heating is provided by using the heat capacity feature of water in winter. Water exposed to solar radiation on the roof loads the heat and transmits it through conduction to the ceiling under the roof. The heat transmitted to the ceiling heats the interior environment by radiation and some convection. The advantages of rooftop ponds are that they are efficient in dry and temperate climates, that they are effective in storing and managing rainwater, that the accumulated water can also be used in fire situations, and that its performance is not affected by its harmony with the building contrary to other passive strategies[7, 22].




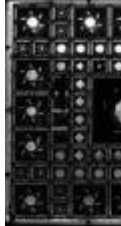


3.3 Increase in Efficiency of Thermoregulative Building Envelopes

Thermoregulation in buildings include heat recovery, conservation of heat, dissipation of heat, blocking of heat gain, natural ventilation and air flow[23]. The most important factor in the zero-energy building concept is that the existing energy resources can be used at maximum efficiency while providing thermoregulation and the building envelope can achieve this harmonization. For this, active technologies that respond to the changing conditions of nature must be included in the building structure. Active technologies include reconfigurable geometry, multifunctional mechanism, dynamic and responsive envelope structure to meet the needs of users in the building[24-26]. Active technologies such as sensors and motion initiators increase the efficiency of passive strategies. The realization of thermoregulation, which consists of three main components: change, control and response, can be achieved by dynamic control[27]. Dynamic control can be achieved by managing the movement and adapting it according to the needs. This situation, which is defined as "modifying the microclimate" in the literature, has created the concept of "kinetic building envelope". Geometry and orientation, which perform three-dimensional shape change in order to manage sunlight and wind, which are the main components of microclimate, are the most important elements in kinetic structures[23]. Changes in form, color, orientation, material changes and optical properties are the features that enable the kinetic structures to stand out with their functions in providing maximum efficiency, by imitating active technologies that enable dynamic movement[28-30]. Examples of

Thermoregulative building envelope studies that provide effective management of solar energy in the building are shown in Table 1.

Table 1. Kinetic building envelope project examples [23]

Project Name	Year	Climate	Characteristic element	Move-ment type	Scale of kinetic element	Function	Indoor environment quality
Manitoba Hydro	2009	Humid continental		Flap	Larger element in façade	Interactive to dynamic daylight, Interactive to wind	Daylight Performance, Control Solar Heating, Air Movement & Natural Ventilation
Thyssen Krupp Cube, Q1	2010	Temperate		Flap Pivot	Larger element in façade	Interactive to dynamic daylight	Daylight Performance, Reducing Glare
Kiefer Technic Showroom	2007	Temperate		Fold	Larger element in façade	Interactive to dynamic daylight, Interactive functional scenarios	Daylight Performance, Control Solar Heating
EWE Arena	2005	Temperate		Slide	Parts or volumes in the façade	Generating energy in façade	Daylight Performance
House at the Milsertor	2008	Humid continental		Fold Slide	Larger element in façade	Interactive to dynamic daylight	Daylight Performance

St. Ingbert Town Hall	2009	Temperate		Fold Slide	Larger element in façade	Interactive to dynamic daylight	Daylight Performance, Control Solar Heating
							
Al Bahar Towers	2012	Warm desert		Fold Expand & Contract	Larger element in façade	Interactive to dynamic daylight	Daylight Performance, Control Solar Heating, Reducing Glare
Institut du Monde Arabe	1987	Temperate		Rotate	Larger element in façade	Interactive to dynamic daylight	Daylight Performance
SDU Campus	2014	Temperate		Flap	Larger element in façade	Interactive to dynamic daylight, Interactive functional scenarios	Daylight Performance, Control Solar Heating
Sharifi-Ha House	2013	Mild, semi-humid		Rotate	Parts or volumes in the façade	Interactive to seasons change, Interactive functional scenarios	Daylight Performance, Control Solar Heating

3.4 Biomimetic Approach for Dynamic Control of Passive Building Envelopes

Biomimetic, which comes out with the combination of the words "bio" meaning life and "mimicry" meaning imitation, means design inspired by nature. Biomimetic approach and design methodology are used as a method to find solutions to existing engineering problems, and the design process can be carried out in two ways. The first is the biomimetic design method from the problem to biology. In this method, based on the engineering problem, the solutions brought by nature to the same problem are examined in terms of function and form, and inferences are made from the teachings obtained in a way that can be applied to the engineering problem. The second is the biomimetic design method from biology to engineering, and it includes solving existing engineering problems, inspired by the solutions they bring to the problems they encounter in their own living environment in order to sustain the lives

of biological structures in nature. At this point, the solutions brought by biological structures and systems that can adapt to changing environmental conditions can be used as a source of inspiration by using the design method from engineering to biology in order to realize the system and structure designs with dynamic functioning that are needed in buildings. Biomimetic systems, which offer solutions based on the fact that the biological structures and systems in nature use the existing energy resources with full efficiency under changing conditions, offer dynamic solutions that come up with the combination of passive strategies and active technologies. In the use of biomimetic approaches in terms of thermoregulation, plants interacting with the environment thanks to dynamic movements and orientations, despite their static structure, constitute examples of physiological, morphological and behavioral dynamical interactions and become a source of inspiration for the provision and development of thermoregulation. In this context, the morphological approach that proposes to make the facade from static to dynamic is the most effective method of biomimetic approaches, and biomimetic studies are mostly on the geometric transformation (transformation) that a system allows morphologically[23] [31] [32].

Biomimetic systems aim to create interactive relationships and behaviors that can adapt to the changing conditions of nature by examining complex, adaptable and transformable morphologies in nature in order to provide dynamic structuring in building envelopes, and to reach maximum performance by supporting this interaction with smart materials. Based on the morphological approach, nature-inspired model, geometry or principles, it provides simultaneous interaction with high performance surfaces in adaptation to nature. Three-dimensional (3D) geometrical changes are among the topics that have attracted attention in recent years due to their contribution to performance improvement in providing thermal comfort[23].

As previous research established, there is a mass concentration on the use of renewable energy in order to reduce energy consumption [33]. This may be as a result of the increase in the world's population [34]. As consistent with previous studies, this research addressed various options that could be used in place of non-renewable energy [35] [36].

4. Conclusion

In the self-sufficient and energy efficient ZEB building concept, the building envelope interacting with solar energy is an important component of the building. Passive envelope strategies play an active role in providing this interaction without the need for extra energy. Increasing energy efficiency is possible with the dynamism that enables the building envelope to adapt to environmental conditions simultaneously and effectively.

Adaptation to different scenarios that come with dynamic sun rays and changing climatic conditions arises the concept of kinetic structure. It is concluded that the types of motion, morphology, geometry and orientation are the most important factors in providing an effective dynamic interaction in the kinetic building envelopes that cover a certain part or the entire building facade and serve as the second layer of the building, and the material properties are the most important supporters of this interaction. This study provides a basis for future studies on the benefits to be obtained by applying the strategies that the creatures in nature tend to use solar energy effectively in supporting energy efficiency in buildings while providing thermal comfort.

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