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GREEN ERGONOMICS, BIOMIMETIC, ENERGY AND EXERGY

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ABSTRACT

Biomimetic approach with energy and exergy analyses presents a great potential for developments throughout the ergonomics field. Actually mentioned concepts are linked to ergonomics in literature with a new term namely green ergonomics, nevertheless the interactions among them are not perceptibly stated; this article aims to fill the gap pending on the matter. In the scope of this article conceptualization of the mentioned subjects regarding with the main elements of ergonomics for office situation is discussed. Energy and exergy flow processes of these systems plays an important role for sustainability, hence a framework for the related analyses is involved in the study. State-of-art in biomimetic applications and new possibilities for the application of biomimetic in the green ergonomics context is examined and novel insights are presented.

Keywords: Green ergonomics, Biomimetic, Energy, Exergy, Sustainability.

1. INTRODUCTION

In the scope of the green ergonomics, human systems' interaction with nature's systems is explored with aiming well-being of the either of both parties. In this regard, biomimetic design concept may contribute to green ergonomics since biomimetic takes its source from nature. Efficiency and effectiveness is concerned with an ecological approach and in particular energy flow of the system with its surroundings is explored from the viewpoint of green ergonomics. When it comes to efficient use of the energy and its flow in the system relative to its surroundings, 2nd law of thermodynamics would become prominent. 2nd law stresses quality of energy rather than quantity and this provides a basis for the exergy approach. Biomimetic approach with energy and exergy modelling of a system might contribute to design process of green ergonomics. In this paper, relations among these concepts are examined in the scope of the green ergonomics.

2. GREEN ERGONOMICS, BIOMIMETIC, ENERGY, EXERGY, AND SUSTAINABLE BUILDINGS

In brief, ergonomics is the science branch which explores the relation between humans and the elements they interact in the workplace while bringing forward the human well-being factor. Physical, cognitive, and organizational ergonomics are the domains of specialization of the branch. Sustainability, sustainable development and ergonomics relation is not so embraced to date [1] and creating new synergies between mentioned domains could bring several benefits. Innovative approaches could contribute to a further advancement in ergonomics discipline [2].

Establishment of Technical Committee for HF/E and Sustainable Development within the International Ergonomics Association structure in 2009 was a concrete step in this manner [3]. Design and engineering approaches are in a continuous transition in this era and new ways are proposed appropriate with the actual challenges that world encounters such as climate change. Several sustainable design approaches are developed in recent years. There is a broad terminology including; green design, eco-design, environmental design, sustainable design, climate sensitive design, low-energy design, bio-climatic design et cetera [4]. The prospect is not very different for engineering; the following approaches are the two examples developed in this manner.

12 principles for “green engineering” are developed [5], these are; (1) ensuring all materials and energy inputs and outputs are as inherently nonhazardous as possible, (2) preventing waste, (3) designing separation purification operations to reduce energy and material consumption, (4) maximizing efficiency in a holistic manner comprising products, processes, and systems for energy, time, space and mass, (5) preferring "output pulled" rather than "input pushed", (6) conserving complexity for design methodology of recycle, reuse, and beneficial disposition, (7) targeting durability as a design goal, (8) minimizing excess, (9) minimizing material diversity, (10) integrating material and energy flows, (11) considering the commercial afterlife and (12) preferring renewable rather than depleting.

By the Sandestin Declaration, 9 principles for “green engineering” are presented; (1) using systems analysis and integration of environmental impact assessment tools with an holistic approach, (2) conserving and improving of natural ecosystems while taking into consideration human health and well-being, (3) benefiting from life-cycle thinking, (4) ensuring material and energy inputs and outputs to be safe and benign, (5) minimizing depletion of natural resources, (6) preventing waste, (7) developing engineering solutions with respect to local geography, cultures, and aspirations, (8) Improving, innovating, and inventing technologies to achieve sustainability, (9) engaging of stakeholders and communities in development stage of engineering solutions [6].

'Green ergonomics' and 'ergoecology' approaches were proposed in the context of integration of sustainable development to ergonomics, and they are currently being developed. Social and environmental responsibilities are identified as leading threads for both; ecological sustainability is the main node and under this there is cultural sustainability comprises technological, economic, political and social dimensions [7]. Green ergonomics is a rather new approach arouse in very recent years. By the introduction of the green ergonomics, the scope is broadened in a manner that ecology is emphasized and thereby human influence on the natural environment and comebacks of the endeavor become subject to investigation.

Biomimetic is inspiration from natural systems and these systems are implemented in three levels; organism, behavior or ecosystem to the models with intent to solve several challenges of human being, Figure 1. Biomimetic has nine principles of nature: Nature (1) depends on sunlight, (2) utilizes only the energy it needs, (3) fits form to function, (4) recycles everything, (5) accolades cooperation, (6) relies on diversity, (7) requires local expertise, (8) curbs excesses from within, (9) taps limit of the power [8]. In the context of sustainability; for a particular product, application of the biomimetic principles could be evaluated for the throughout lifetime of the product, namely for the design stage, the manufacturing stage and all the useful life and disposal of the mentioned. A sustainable method should also comprise designing for recycling and reuse [9]. In this regard, in order to avoid from confusion, inspiration from nature doesn't mean that the revealed final product is thoroughly sustainable in every case.

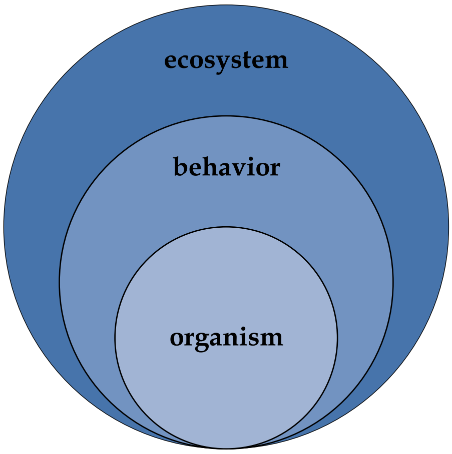

Figure 1. Three levels of biomimetic

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There is a reference to energy and exergy subjects and involvement of biomimetic in ergonomics in recent studies, but the relations among these and how they are assessed in a system is not clearly examined. First of all, for an exergy analysis of a system, boundary conditions should be determined. Briefly, elements of ergonomics could be determined as human, machine-equipment and workplace, Figure 2. Workplace can be indoor or either outdoor.

Relatively for indoor situation, the system could be determined as the space including the walls of a room. Then energy and exergy flows of the system are determined. It is obvious that several individual elements of the room such as an electronic device also can be selected for exergy analysis, and analysis can be performed for that standalone element.

According to 1st law of thermodynamics, energy can flow into a closed system as heat, work or mass. Finally, energy input into the system and energy consuming devices are identified and energy and exergy equations of the system are derived.

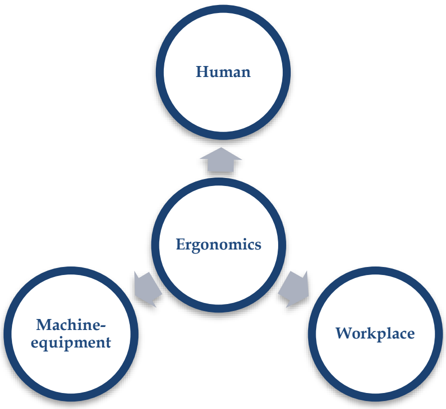

Figure 2. Three elements of ergonomics

Exergy is the “extractable work” from a process, substantive with ambient conditions, consumable, directly related with irreversibility and regarded as a key factor for sustainability.

An instance for energy gains and losses (or consumption) for an indoor system is given by Table 1 [10], the exergy relations then might be derived.

Table 1. Energy gains and losses in buildings [10]

Energy gains	**Energy losses (or consumption)**
▪ Power plant ▪ Solar energy, passive use ▪ On-site generators, solar, wind, biomass etc. ▪ Occupants ▪ Electric devices ▪ Lighting systems ▪ Specific heat gains from internal devices	▪ Lighting systems ▪ Electric devices ▪ Heating and cooling systems ▪ Ventilation ▪ Transmission, radiation; walls, ground, roof, windows

The concept investigated in this paper is given by Figure 3.

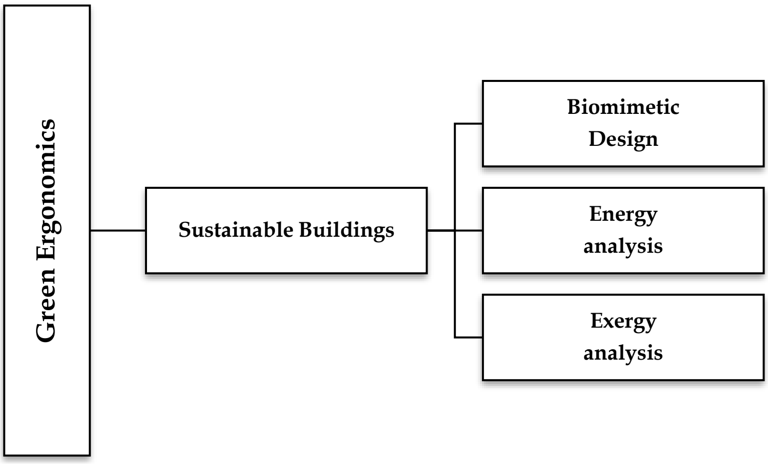

Figure 3. Green ergonomics concept for indoor environments

International Energy Agency grouped the exergy measures under 4 subtasks in Buildings and Communities Programme EBC Annex 49, [11]. These are as following: Subtask A; exergy analysis methodologies, Subtask B; exergy efficient community supply systems, Subtask C; exergy efficient building technology, Subtask D; knowledge transfer, dissemination. Here Subtask B encourages developing innovative technologies for energy supply systems for different exergy values, innovation of technology for local possibilities such as renewables and advanced technologies for local generation and distribution and storage of energy and exergy. Subtask C recommends innovative technologies for low exergy cooling, heating and ventilation systems. It is obvious that innovative design is needed for exergy & building subject; in particular, for low exergy design. In the exergy context, main objective for a building is providing comfort with minimum consumption; in another words effective exergy management in order to match the quality levels of the

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supplied energy to demand. Importance of exergy is based on the fact that it is regarded as a key factor for sustainability. Nonetheless, high exergy resources such as fossil fuels are consumed widely in order to satisfy the needs of the buildings. For example, low temperature heat sources such as ground heat, solar heat or waste heat can be utilized for space heating needs. High grade energy should be directed to sectors such as industrial production where high exergy levels are needed. The exergy requirement is rather very low for the heating and cooling demands of buildings; a room temperature around 20 °C is convenient, unfortunately high quality energy resources are exploited for to fulfil this low exergy requirement [12].

From the exergetic view, exergy quality respectively in order to achieve 20 °C room temperature is 7%, for domestic hot water at 55 °C it is 15%, for cooking it is 28% and for the operations of the lighting and household appliances it is 100%, therefore it is noted that the largest energy requirement ratio for a building is to meet the heating demand. Figure 4 illustrates how energy and exergy reduce from transformation to final use [12], it is clearly understood that the ratio of primary energy consumption should be reduced in order to reduce exergy consumption.

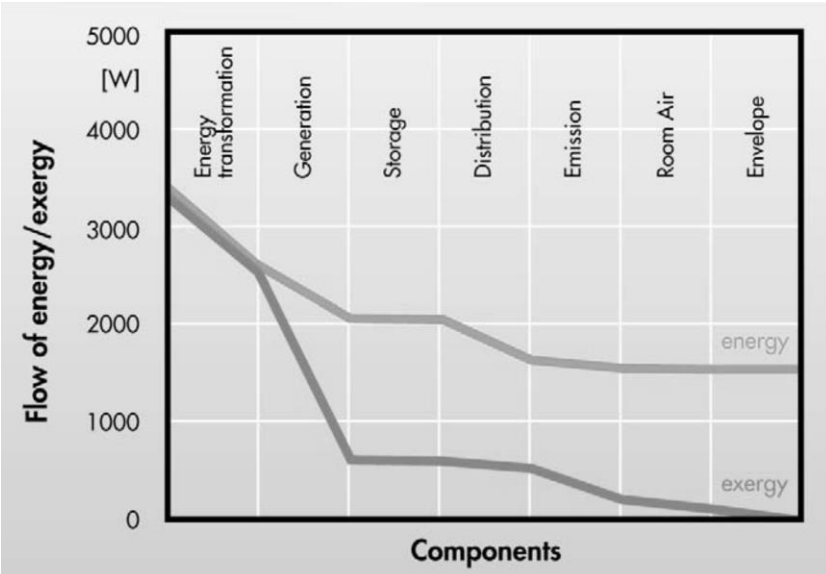

Figure 4. Results of energy and exergy flows analysis of a building [12]

According to [13] a building is an open thermodynamic system; it interacts with the environment in terms of energy and material fluxes. Researchers defined a black box model and restricted the field with a building. Materials and air are the elements of the system but human body is excluded. As regards to their model; (a) natural gas, cold water for sanitary use, human thermal energy, electricity (lighting and appliances), solar radiation, air flux for natural ventilation, heat flux through the building envelope are input exergy fluxes of the system, (b) air from gas combustion, hot water for sanitary uses, air flux for natural ventilation, heat flux through the building envelope are exergy fluxes or losses from the system. It is stated that 95% of the exergy is destroyed and the exergy loss ratio is 5%. In [14] CFD simulations are carried out. Humidity, carbon dioxide and heat sources are defined in the model to account for the impact of occupants, and as well as convective, radiative heat transfer for walls or through windows. The supplies of fresh air, walls, windows, temperatures are stated as boundary conditions.

An exergetic assessment was performed for an educational building in İzmir province of Turkey [15] that exploits a conventional boiler for heating and system is analyzed for the whole process; generation of energy from primary source to building envelope. Exergetic efficiencies of the conventional boiler were found as 13.4% and 37.6% for the fan coil unit and total exergy efficiency was stated to be 2.7%.

The importance of insulated building materials is emphasized to support low exergy heating systems. A variable air volume system for air conditioning of a large office building in Montreal was studied in [16], according to 1st law, building has a low performance, and additionally exergy efficiency is found as considerably low: 2–3%, and 97–98% of the exergy is wasted. It is stated that enhancement in exergy efficiency is obtained by switching the energy source for heating from electricity to renewables.

In [17] interactions between building systems and human body are investigated in the context of exergy analysis. According to the results the reduction in exergy consumption rate within building envelope systems is approximately 99.7%. Thermal insulation is embraced for four different climates around the world. Thanks to insulation, interior surfaces of building envelope system emit 'warm' radiant exergy into the room in cold climates, and in hot-dry and hot-humid climates it allows to emit cool radiant exergy but not warm radiant exergy. It is stated that the human body exergy consumption decreased with thermal insulation in all relevant climates.

In [18] an exergy model of human body in office conditions for winter season is studied with a simulation. It is found that optimal human performance corresponds to minimum exergy consumption of human body and it occurs under thermal conditions that makes a sensation close to slightly cool.

In [19] four different alternative designs for a building block in İzmir are investigated in order to compare the exergy efficiency alteration with the actual design. According to design it is shown that exergy efficiency value is raised from 1.5% to 12%. Also exergy load of a single house unit dropped from 1800 W to 137 W in winter and 3180 W to 346 W in summer. These values show the impact of the appropriate urban planning on the exergy savings.

OECD carries out sustainable buildings project that aims to design buildings those have lower adverse impact on natural or built in environment, respectively building themselves, their surroundings, regional and global settings.

Five objectives are specified in this context; (1) increasing resource efficiency, (2) increasing energy efficiency, (3) preventing pollution (air quality and noise abatement are included), (4) providing harmonization with environment and (5) developing integrated and as well as systemic approaches [20].

Several assessment methods and certification systems are developed for rating the environmental performance of buildings; in a broad sense these methods also might be evaluated under the sustainability context. Thatcher and Milner explored three buildings those are certified from a building sustainability rating system Greenstar SA; one of these buildings has a five stars rating and other two have four stars [21]. According to results, most important factor is found as ventilating and air quality for the well-being, researchers advocate that thermal comfort can be personally controlled.

According to study, a green design building that involves indoor environmental quality doesn't mean that it is environmentally sustainable and likewise an environmentally sustainable design may not be appropriate for well-being of occupants. Leadership in Energy and Environmental Design (LEED) is a certification system that is very related to green design concept. LEED certified buildings as being energy efficient should provide the comfort and well-being of occupants [22].

According to LEED rating system there are six categories; sustainable site, water efficiency, energy & atmosphere, materials & resources, indoor environmental quality and innovation & design process. LEED certification system gives one point for a good ergonomic program and design, as an instance some of the requirements for the third criterion is using antiglare devices, the chairs should be optimized for employee fit and task requirements and have a wide range of adjustability [23].

Four criteria should be met in order to earn this point; (1) design has to identify activities and functions of the building for ergonomic enhancement through education and equipment, (2) performance goals and expectations should be defined for strategy of ergonomics, (3) design must provide equipment, tools, machines, accessories, furnishings, work-aids those are convenient for a wide range of occupants and reduce the risk of musculoskeletal disorders related to work conditions, (4) occupants should be educated about ergonomics.

An internet survey about indoor environment and ergonomics issues of 44 occupants of two LEED Platinum buildings is reported by [24]. According to results, in general these buildings were a positive experience for their health, performance and satisfaction.

Problems related to noise and air quality are reported, and ergonomics design issues were also detected only in one building. The factors subject to this evaluation are overall workstation, office furniture, daylight, office lighting, noise, air quality, fresh air and air temperature. The researchers stated that green building designs should be more involved in ergonomics and certification systems should better incorporate with ergonomic design. According to case study carried out by Liu, Li, and Yao, 70–80% of the environmental impact originates from the energy consumption for a building lifecycle of 50 years, and 20–30% of that comes from the discharge of the pollutant [25].

3. BIOMIMETIC STATE-OF-ART AND FUTURE INSIGHTS

In recent studies biomimetic is considered as one of the factors involved in green ergonomics subject, but its relation with green ergonomics and energy, exergy and how they are assessed in a system is not clearly examined. The indoor environment of a building comprises several factors and their various aspects should be considered, namely indoor environmental indicators such as air quality, electromagnetic fields, vibration, acoustics, lighting, visual comfort and thermal comfort [26].

In detail, wall color, adjustable chair and work area design are considered measures for office ergonomics [27]. In general low energy systems and products and thus in this scope green buildings' siting, materials, heating and ventilation, layout, construction are subject to green ergonomics [28]. Ecological systems may not be efficient however they are effective in capturing useful energy such as solar radiation. Thus the exergy approach might be more appropriate for mimicking ecosystems. Buildings need constant flow of high quality energy [29]. According to [30] ergonomics and sustainability should be evaluated together with green technologies, resource consumption would be reduced and it has benefits to productivity of human with high satisfaction regarding environmental variables for overall comfort, lighting, temperature, and air quality. In this section, application of biomimetic approach in the scope of green ergonomics is discussed. State-of-art for each category is given at the beginning of each section. After that new insights are presented, some of them could be evaluated within biomimetic concept while others are related to energy, exergy and biomimetic. A further research can be carried out under one of these categories according to the goals and expected results for the designed system.

3.1. Workstations

Chairs, tables and accessories such as document holders are the main elements of an office those are subject to ergonomics. A chair might contribute thermal insulation of the body by 0.3 clo by an appropriate design and this value corresponds to difference between the impact of summer and winter clothes [31]. An instance of an ergonomic chair design is the egg shell inspired from strength of an egg. Reduction in material amount gained in addition to comfort, flexibility and adaptability, Figure 5 [32].

Figure 5. Egg shell chair model [32]

Diatoms are one of the members of plankton organisms which have lightweight composite material shells those are mechanically very strong. The structures and as well as material properties of them could be used for lightweight furniture that consume lower energy in manufacturing stage [33]. Silk of European garden spider (*Araneus diadematus*) is light-weight, extendable (40%) and has a high tensile strength (≈1200 MPa) [34]. There is an opportunity to use for furniture such as chairs. Phase change materials (PCMs) are the other materials to use in furniture. This phenomenon is observed in some animals such as dolphins, fatty acids found in blubber are PCMs and their melting points are in the range of mammalian body temperatures [35].

When used in chairs, PCM may absorb human body heat and release it in low temperature conditions. When it is used in tables, it absorbs the ambient heat and releases it when the temperature of environment is dropped. This phenomenon helps to regulate ambient temperature. Ultimately, in this context innovation is finding out appropriate PCMs (organic, inorganic or eutectic) and adapting them to workstation elements appropriately with their thermophysical properties.

3.2. Clothing

External factors such as clothing and seating affect the thermal comfort of the human body. Development in textiles is subject to clothing for thermal comfort can play role on energy savings for the amount used in buildings. “Cool Biz” programme was implied in Japan in 2005, thermostats were set at 28 °C at the offices, and a dress code for clothes such as no-suit and no-tie are allowed. Approximately 1.14 million ton reduction in CO_2 emission is achieved consequently [31].

Development of smart textiles for thermal regulation of the body can contribute a considerable amount of decrease in energy consumption. Intelligent textiles, also known as smart textiles interact with environment and perform predetermined actions and repeatedly as well as reversibly [36].

Active smart textiles including PCMs absorb heat when the temperature is high and release heat when the ambient temperature decreases under the PCMs' melting point. Surplus heat released from body is absorbed and it creates a cooling effect, thus this microclimate temperature is kept in a desirable comfort zone.

When submerged, 22% of the required oxygen of yellow bellied sea-snake is met through its skin by gas exchange [37], also there occurs a heat exchange, this mechanism could be adapted particularly for the heat regulation in clothes. Also thermal insulation solutions given in the 3.4.1. section could be implemented in clothing if proper.

3.3. Indoor Heaters

Conventional heaters for buildings utilize electrical energy or energy from fuels. Electric resistance space heaters convert all the electrical energy to heat; consequently, energy efficiency is 100%, however in theory same amount might be achieved with only one-tenth of the input energy. This adds up that the exergy efficiency of this type device is lower than 10% [38]. This field is convenient for developments in terms of exergy.

The energy mix structure is important for electrical heaters that depend on the energy from the grid; if the system depends on thermal power plants, it is obvious that the main exergy losses occur during the cycles in thermal power plant. Inspired from lobster eye, reflective lens radiant heaters were designed [39], Figure 6. In spite of heating all the space in a room, this device directs the energy by focusing.

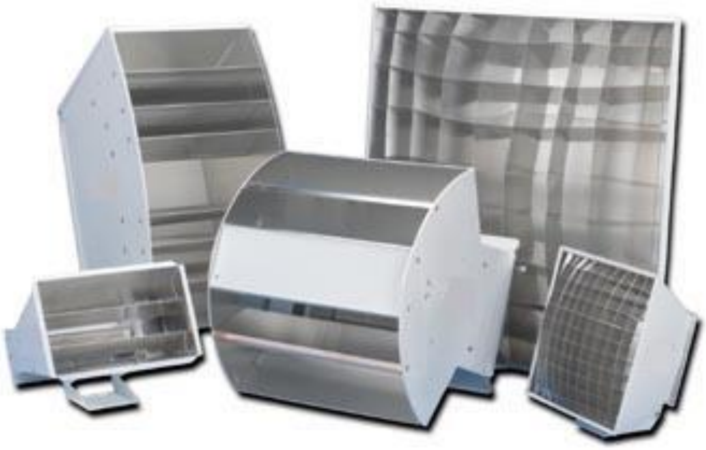

Figure 6. HotZone™ radiant heater, uses IRLens™ [39]

Heating is the major energy consumption factor for buildings in cold climate conditions. One of the rewarding field is the design of renewable energy sourced heaters in this context. Solar energy could be integrated to biomimetic heater designs.

In heating, heat exchangers are the prominent components of the systems. Tongue of baleen whales and gray whales have a counter-current heat exchanger system, lingual retia to lower the heat loss [40] and this could be adapted to heating systems.

3.4. General Building Design

Upper Riccarton Community and School Library minimizes consumed energy by air conditioning systems with its eco-efficient design [41]. Nature inspired principles are implemented for overall design of the building; thermal mass is located carefully, and roof-mounted extractor fans augment passive ventilation at the times of peak temperature, the ventilation mechanism is responsive to sunlight and temperature.

The 'Biomimetic Office Building' is asserted to be the first one comprehensively designed with totally biomimetic approach. Mimicked life forms in this conceptual design is given in Table 2, this building is predicted to be one of the lowest energy consuming office buildings of the world [42], Figure 7.

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Table 2. The Biomimetic Office Building [42]

Design approach	Life form
Daylighting	Spookfish, stone plants
Structure	Bird skulls, cuttlebone, sea urchins, giant amazon water lilies
Environmental control	Termites, penguin feathers, polar bear
Solar shading	Mimosa leaves, beetle wings, hornbeam leaves

Figure 7. The Biomimetic Office Building [42]

Biomimetic state-of-art and novel implementation possibilities are given in the following sections in detail proper with the categories.

3.4.1. Thermal Insulation

Polar bear has to survive in arctic climate; at temperatures around -50 °C. It has a fat layer up to 0.1 m thick provides protection from cold environment. Bear has a black skin and its white yellowish white hollow hairs reflect the sunlight along their length which is converted to heat by the black skin of the bear, Figure 8, [43].

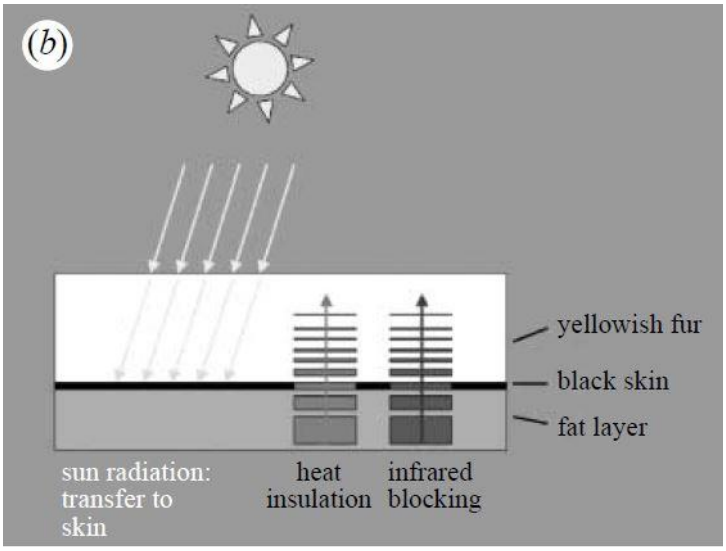

Figure 8. Schematic of polar bear fur [43]

Duck feathers have a thermal insulation feature; it is attributed to trapped air exists in their structure. Eadie and Ghosh studied synthetic structures mimicking the duck feather [44]. Inspired from the fur, modelling of fur on external wall of a building is proposed by [45].

It is found that artificial fur may provide a radiative and insulative barrier for the heat transfer. Layer thickness, fibre number per unit, angular orientation of fibres of fur are variables which are optimized. The thermal conductivity is reduced to 0.55 W/mK. A fur coated façade reduces heat load up to 50% for a summer season. In their study, a thermal model of heat transfer is constituted by Dawson et al [46].

Standard theory is used for the model thanks to uniform distribution of the feathers and their associated afterfeathers. It is found that convection does not occur. Radiative heat loss is minimum and there remains conductivity. The theory predicts a thermal conductivity of 2.38 W/m^{2}K that compares well with measured empirically value of 1.93 W/m^{2}K. Human body keeps the internal temperature near 37.2 °C, in addition to this, every organ has a specific temperature for effective function [47]. This adds up to an internal thermal variation. A breathing wall concept is proposed in the mentioned study.

There are three layers; external layer is capable of preventing sunlight, it can absorb moisture and allow air to pass, the middle layer corresponds to epidermis of human skin. By this layer, thermal insulation, cooling of airflow by geocooling or evaporative cooling is provided, internal layer comprises controlled ventilation outlets managed by occupant or management system of the building. The reduction in the internal temperature is found as 5 °C in

T_{max} and 8 °C in T_{min} by the field experiment. Researchers proposed a comprehensive system for thermal comfort inspired from a desert snail's (*Sphincterochila boissieri*) several survival methods [48].

By withdrawal into shell, snail avoids from direct solar exposure. Its shell reflects light and thus the snail is protected from solar radiation; it has a white cover and reflects 90% of visible light and 95% of infrared radiation. It creates a shadow by its shell and less heat transfer occurs by conduction. Snail withdraws inside the shell and thus air between the snail and ground provides insulation.

Thermal regulation is provided by the alteration of water content of the snails in the day due to evaporative cooling. The property of the shell is adapted to building roof by the proposed strategy. The insulation by air property of snail is mimicked by aerogel insulation in the form of flexible blankets, in that 90-95% of aerogel is air and insulation provides a low thermal conductivity. The snail's shell composed of three whorls that have different temperatures and a similar layering system is proposed; by this the main office is separated from external environment and 3% reduction is provided in cooling loads. Structural measures are also proposed for shading and natural ventilation. Researchers focused on plants in order to offer innovative façade design solutions for buildings, as they lack of movement such as plants [49].

Mesembryanthemum seeds have a valve mechanism and star-shaped set of valves open with rain fall. This is adapted to building envelope to reduce number of construction elements and autonomous activation with rain fall [49]. *Salvia officinalis* reflect the light with the three dimensional waxes and with air filled hair coverage, this could be used in building envelopes to protect from excessive heating due to sunlight. Micro-greenhouse effect; a special cooling effect is observed in *Galanthus nivalis*, their flower petals have a special retro-reflecting property, in order to drop building surface temperatures, they could be retrofitted with a bio-inspired retro-reflective façade application [50].

The tree bark has an insulation property; the cambium behaves such as an insulation layer. This property could be transferred to biomimetic materials [51]. Arctic animals such as polar bear survive in very harsh conditions. While fur and feathers insulate in air, layer of fat or blubber insulates in water. For blubber of phocids thermal conductivity is 0.192 ± 0.040 W m^{-1} $°C^{-1}$; and for otariids this value is 0.276 ± 0.068 W m^{-1} $°C^{-1}$ [52], blubber inspired insulation materials could be developed to use in walls, floors or ceilings.

3.4.2. Dehumidification

Researchers focused on the Spanish moss in order to develop a passive indoor dehumidification system [53]. The pore geometry of Spanish moss creates differences in vapour pressure and automatically absorbs water. The gaseous molecules passively diffuse and then condensate due to size and shape of pores that is to say capillaries convey the water to where it is needed, this is called capillary condensation. This is mimicked by a ceiling structure with pores that attracts water from the room air in the study, and these pores transport the water to capillaries and produce a passive dehumidification process.

Natural hydrophilic surfaces attract water while hydrophobic surfaces repel water. A surface with hydrophilic tips and hydrophobic channels could be a model to catch water and then collect as it is performed by Namibian beetle (*Stenocara gracilipes*). Sand lizards absorb moisture from air by hygroscopic skin [54]. Australian thorny devil, (*Moloch horridus*) has a micro-structured skin pattern with capillary channels that provides acquisition of water from natural sources such as dew or rainfall [55]. Plants lose heat by transpiration while animals regulate temperature by evaporation. Plants with thick external layers and also waxy coverings reduce heat transfer. Leaves absorb and store water; animals insulate with coloration. Plants avoid heat gain via their lower leaf area and decrease sunlight absorption.

Adsorbent materials play an important role for development of desiccant dehumidifiers. Main adsorbent materials are molecular sieve, silica gel and some clay types such as montmorillonite. Anyway, energy is required for heating of the desiccant, and energy should be obtained from renewables. For adsorbent materials the scientific research is rare but this field is promising for future biomimetic innovations. Tardigrades have the ability to tolerate almost complete dehydration [56]. Anhydrobiosis in organisms such as tardigrades also can give inspiration for the dehumidification process [57].

3.4.3. Sound Proofing

Norwegian reindeer moss with its sound proofing properties, is used in walls for a natural sound proof solution, Figure 9. Commercial product with its name ‘green wall®’ panels perform as ceiling, wall panels, room divider or in free form. They give a green feeling with their soothing and ecological display. Alternatively, this has a potential to produce materials resembles to moss to use as insulation inside walls.

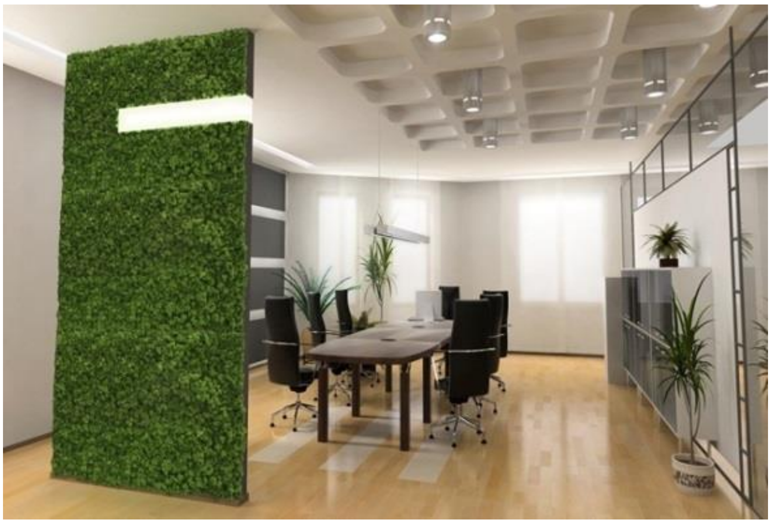

Figure 9. Green wall® [58]

Cattails possess potential as an insulation material. Leaves of cattails are made up with fiber-reinforced supporting tissue inside filled with a soft sponge tissue. The researchers created a panel composed of cattails that has a soundproofing with low heat conductivity of 0.052 W/mK [59]. A class of lightweight honeycomb acoustic metamaterial that has sound-proof properties is designed by Sui et al. which has a small mass per unit area (1.3 kg/m^2) and might achieve low frequency (<500 Hz) sound transmission loss perpetually greater than 45 dB [60]. Fractals topic is one of the research field that biomimetic deals with. Fractal geometry was applied to a sound barrier, and patented as fractal wall® which includes holes ranging from 30 cm to submillimeter pores. This wall absorbs acoustic energy on average 98% of the audio spectrum [61].

Heat insulation materials improve the sound proofing but they don't replace specifically designed materials for sound insulation. Actually sound proofing is provided by porous absorbers, panel absorbers or resonators. Porous materials ensure acoustic absorption; waves are received and soaked up. The porous patterns found in bone cell formations, sponges, branching structures such as lichens, seashell wavy outer layer patterns could be mimicked for insulation materials. Diatom patterns could be investigated for resonator geometries.

3.4.4. Lighting

Lighting consumes a considerable amount of energy and it is inefficient. Electromagnetic radiation has similar exergy and energy contents. For incandescent lighting energy efficiency is 5% and for fluorescent this value is 20% respectively [38]. Living organisms emit light by three different mechanisms: bioluminescence, phosphorescence, and fluorescence.

Bioluminescent organisms produce visible light by a chemical reaction and they cover a broad species such as terrestrial and marine animals, fungi, bacteria and other microorganisms. Bacteria *Aliivibrio fischeri* has a bioluminescent property [62] and it is commercially utilized by filling small transparent cases with a gel that has nutrients; researchers currently study on genetics of the bacteria to pass the 3 days' threshold for to keep bacteria alive. The genes of bioluminescent organisms might be inserted into the plants also.

Fluorescent organisms absorb light and reemit in a different color (wavelength). Phosphorescence resembles to fluorescence yet it lasts longer. Sea sapphires have a distinctive shining mechanism. They have tiny layers of crystal plates inside their cells and only reflect light within a limited range of wavelengths. In case of the blue ones, crystal layers are separated in same distance with blue light wavelength, so blue light is absorbed and reflected afterwards. These mechanisms could be studied for exploiting daylight and developing effective lighting systems. They could be also developed for visual comfort such as wall paints or other elements of office.

3.4.5. Ventilation

Inspired from termite mounds, natural cooling is applied in the well-known Eastgate Centre. Mound catches the breeze and flues vent through the top and sides of the mound, hot air from the main chambers in below parts is drawn out by the wind; this phenomenon is also known as 'stack effect' [63]. Human nose modulates the temperature of the atmospheric air passing to the respiratory system by moisturizing or by capillaries, in addition to this, it filters the air. Honeycomb permits daylight with its large volume and allows air flow to pass through it. Cacti plant reflects direct sunlight to provide shade and increases heat radiation. The suggested "Breathing Window" by [64] is designed by inspiring from the mentioned features; it increases shade, reduces heat gain around by reflecting direct sunrays, cools and filters air flow passing through the window by evaporative cooling phenomenon in summer. In winter, it filters the air, permits direct sunrays to pass through window, and spreads light and heat. Governing mechanism in order to regulate nest climate was investigated by Kleineidam, Ernst, and Roces [65]. There exist two distinct tunnel groups: outflow tunnels in the upper, central region, and inflow tunnels in the lower part. Surface wind drawing air from the central tunnels of the *Atta vollenweideri* nest mound is the primary driving force for the nest ventilation; thermal convection is the other possible driver during summer.

Ventilation can occur either in two ways; natural or mechanical. For mechanical ventilation systems' fans, aerodynamic structure of plants such as maple seeds or ash tree seeds, wings of flying insects and birds could be investigated for more efficient design possibilities. A summary for this section is given by Table 3.

Table 3. Biomimetic solutions for ergonomics; state-of-art and new insights

Category	State-of-art	New Insights
Work Stations	Egg	Diatoms, spider, dolphin
Clothing	Dolphin	Yellow bellied sea-snake
Indoor heaters	Lobster	Baleen whales, gray whales, renewable energy integration
	Building Design	
Thermal Insulation	Polar bear, duck, desert snail, *mesembryanthemum*, *salvia officinalis*, *galanthus nivalis*	Tree, arctic animals, seals
Dehumidification	Spanish moss, Namibian beetle, sand lizard	Further research required for adsorbents, tardigrades, renewable energy integration
Sound proofing	Norwegian reindeer moss, cattails, honeycomb, fractal geometries	Bone, lichens, sponges, diatoms
Lighting	Bioluminescent organisms	Fluorescent organisms, phosphorescent organisms, Sea Sapphire
Ventilation	Termite mound, human, honey comb, cacti plant, *atta vollenweideri*	Maple, ash tree, flying insects, birds

4. DISCUSSION

Interactions among the green ergonomics, biomimetic, exergy and energy and as well as their subsequent elements is examined in this paper in the scope of sustainability. The focus is put on the office ergonomics here, and this category covers a considerable amount of energy and exergy related issues. Design could consider an object (e.g. indoor heater) or a system (e.g. whole building with its contents) that comprises different objects within its structure.

After specification of the case biomimetic possibilities are investigated and implementation level of biomimetic is considered. Synchronously, the energy and exergy procedure of the design is modeled if pertinent to case. In case of an energy consuming product, renewable energy integration possibility to the design is assessed either externally or integrally. In case of a system design such as a building, on-site integration of the renewable energy generating plants should be considered. Estimated impacts of the product on the ecosystem are determined with the life cycle analysis procedure.

Studies on biomimetic for sustainable product design are rare. Besides biomimetic, cradle to cradle design and eco-design approaches also might be considered for further studies. Cradle to cradle design takes nature as a model for designing things and aims to achieve eco-effectiveness based on three principles; waste equals food, utilizing solar income and celebrating diversity [66].

Eco-design focuses on three environmental categories; materials, energy and waste. This approach promotes increasing recyclability, utilization of renewable resources and reducing the creation of toxic materials and energy consumption [67]. Ultimately a more detailed framework is required for the sustainable ergonomics.

Anyway design and life cycle are important for products or systems in every area, however in ergonomics the elements subject to design in individual or system level contact more with humans so they should be more intensive. Energy consumption should be considered not only for system service period but for system's production and decommissioning stages, in other words energy demands should be considered for sustainability [68].

5. CONCLUSIONS

In this article, novel insights for biomimetic applications are investigated and presented. Optimized designs should be considered for a sustainable future. Biomimetic approach presents opportunities in a wide range of fields and as well as in order to solve actual challenges in ergonomics field and to actualize further developments. When applying the principles of inspired form to actual design, its impact on environment and contribution to sustainability should be investigated.

As it is stated before in this article, application of biomimetic doesn't always denote a completely sustainable and harmless product in terms of ecology. Besides energy analysis, exergy analysis enhances the design for the efficient utilization of the energy.

Renewable energy integration to further designs would contribute to ecosystem and as well as economy. Besides, a detailed framework is required for the sustainable ergonomics; as the studies on the subject are generally in social sciences, a multidisciplinary approach is needed to draw the cluster for the green ergonomics exactly and to determine the boundaries.

In a systematic design approach context, the approach touched upon here will be a pathway for sustainable designs for further studies. Outdoor environments or other indoor work places such as factories could be investigated specifically in future studies in the scope of green ergonomics.

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