A Review on Sustainable Air-Cooling System Using Biomimicry

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Abstract - *Air conditioning in malls and in other high-rise buildings is a must have feature. One of the major challenges faced due to this is the high amounts of electrical energy needed. It is recognized as an expensive feature of buildings worldwide. Removing air conditioning is not possible due to intolerable temperatures, uncomfortable breathing and problems caused to machineries because of improper heat removal. To achieve this, a sustainable system can be utilized to cut costs which are lost in air-conditioning energy money. Also, air conditioning installation and repair costs can be saved by this method. This is achieved by construction inspired from nature (biomimicry). Termite Mounds are used as an inspiration for this method. Termite mounds or nests work like a giant lung. The structure looks solid from the outside but has tiny holes which enables it to inhale and exhale as temperatures rise and fall.*

Key Words: sustainable system, electrical energy, air-conditioning energy money, termite mounds

1. INTRODUCTION

Human ingenuity has brought humans far from what once they thought they could do, harnessing energy and utilizing nature's resources for solving their problems for approximately 50,000 years now. But however, nature's far ahead of us, tackling the similar problems with ease for over 3.8 billion years. For generations, designers, biologists, medical researchers, and engineers have turned to nature for inspiration. In the past 30 years, driven by the urgency of finding sustainable alternative methods for consuming and producing, there has been an increase in imitation of functions of organisms and ecological processes. This is called biomimicry (it is a combination of 2 words – bios and mimesis – the former means life and the latter means imitate). It is the process of imitating the ingenuity in nature to solve human problems. Biomimicry is not new. The first airplanes were inspired from avian biomechanics. But the biologist, Janine Benyus coined and popularized the field of biomimicry in the early 1980s. She argues that we can improve everything from product design to agricultural production to antibiotic development by just examining the nature's processes. This was an inspirational wakeup call and application of biomimicry has increased since. The phrase "What would nature do?" is becoming a quite common sight in innovation magazines and blogs. A prediction by the Fermanian Business and Economic Institutes suggests that biomimicry research grants and patents could account for 425 billion dollars of US GDP and 1.6 trillion dollars of total global output by the year 2030. By mimicking the nature, it is possible to develop built environments that work collaboratively with nature as opposed to adversely with nature. Due to the toxic and highly energy consumptive systems that humans have historically created, it is time now to look towards the nature and solve the major problems like rising CO2 levels, changing climate and high requirement for food and water for the increasing population. Here, light is shed upon the case of Eastgate Centre in Harare, Zimbabwe and how it's Project Architect, Mick Pearce designed the same while addressing the major issues like heat control, energy expenditure and air-conditioning all of which are expensive and how he tackled all these problems.

Fig - 1: Eastgate Centre, Harare, Zimbabwe

Source: Termite Mounds – Bioinspired Examination of the Role of Material and Environment in Multifunctional Structural Forms | 2018

2. EASTGATE CENTRE: A BUILDING INSPIRED FROM TERMITE MOUNDS

The Eastgate is an office cum shopping complex with a dimension of 140m by 70m. It was opened in 1996 and it consists of 2 narrow East-West oriented 9-storey blocks. These 2 blocks are linked using 4 set of steel bridges. The orientation was chosen as such so as to reduce solar gains on the north-south facades. Limiting the capital and running cost while increasing the thermal comfort was the main aim of the chief architect, Mick Pearce. Being a Zimbabwean citizen, he was aware of the weather conditions and decided to implement biomimicry for a sustainable construction practice. Usually, AC costs comprise up to 15-20% of the construction cost and furthermore costs are added up due to maintenance of these HVAC systems. To reduce this cost while achieving ambient temperatures, Macrotermes michaelseni (a species of termites) were used as an inspiration as they were able to keep their nests at a constant temperature of 87-degree Fahrenheit so as to cultivate fungi in order to convert wood into digestible nutrients.

Fig - 2: Eastgate fills a city block

Source: The Arup Journal, Volume: 32 | January - 1997

2.1 Problems Faced by Termites

Termite mounds face the same problems as tall buildings. People inside tall buildings as well as deep mines suffer from lack of oxygen. The highest termite mounds reach up to a height of 10 meters. So, they face the similar problem. The food they eat develops fungus and causes the release of CO_2 which can suffocate the termite colony if it builds up. The mound acts like a giant lung to keep the air fresh. The sun heats up the outer chambers rapidly than the core during the day which causes the air to move up the outside and down the middle. This process reverses during the night as the outer chamber loses heat while the core retains it. CO_2 and O_2 are exchanged through tiny holes on the outer chamber throughout the day. This enables termites to create huge ventilation engines powered by nothing but daily temperature cycles. Termite mounds are structurally very diverse. This is because the different species use different construction techniques depending on their local environment. There are two types of ventilation models:

- Thermosiphon flow: Martin Luscher developed this model in which the major theme is metabolism-driven circulation of air. Here, the termite colony's heat production is enough for imparting buoyancy and lifting the air inside the nest and out the porous surface of the mound. Water vapour and spent air is exchanged with atmosphere using porous walls and the refreshed air is pushed downward into the open spaces below the nest because of its higher density. This mechanism was assumed to be operated in those mounds where no obvious openings are present.

- Induced Flow: It is also called the stack effect and it was presumed to be operated in open chimney type mounds. As the chimneys are located at a higher location when compared to lower placed openings, they would be subjected to higher wind velocities. This enables a process called the Venturi flow by which the fresh air is drawn into the mound through the ground openings, then through the nest and then out through the chimneys. This flow is considered unidirectional and is dissimilar to the thermosiphon flow.

Mick Pearce intelligently used both the flow principles simultaneously. The row of tall stacks of the building that open up into voluminous air signify the use of induced flow. On the contrary, the heat of occupants, machinery along with heat stored in the thermal mass helps drive a thermosiphon flow from shops and offices towards the roof.

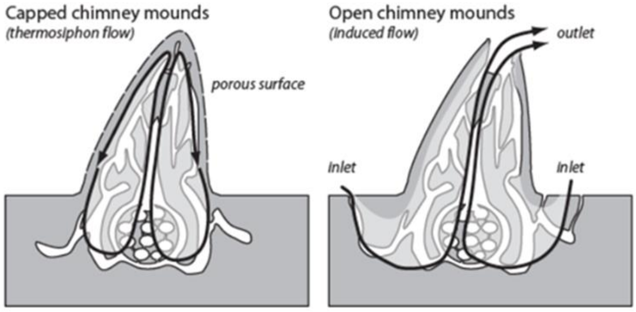

Fig - 3: The 2 types of flow principles

Source: Beyond Biomimicry: What termites can tell us about realizing the living building | May - 2008

2.2 Dissimilarities from termite mounds

Even though the Eastgate Centre is often praised for its impressive thermoregulatory abilities in the architectural literature, there is no scientific evidence that termites regulate the nest temperatures. After closely tracking the nest temperatures of Macrotermes Michaelseni (a species of termites) it was found that nest temperature was about 14 degree Celsius in the Winter and about 31 degree Celsius in the Summer, a difference of about 17 degree Celsius. This proves that the nest temperatures are not affected by ventilations but are strongly influenced by the thermal capacity of soil because they are embedded in deep soil. Similar to the termite mounds, the Eastgate utilizes the thermal capacity of concrete to reduce temperature variations throughout the day. But in the long term, this method is ineffective. So, the Eastgate uses low-capacity fans during the daytime and high-capacity fans during the night. During warm days, the low volume turnover of air facilitates heat storage in the building's fabric, keeping the internal temperatures cool. During cold nights, the high-capacity fans extract stored heat from the building's high-thermal capacity walls. Even though Eastgate can manage without an air-conditioning plant, it definitely needs a fan system to drive the daily ventilation cycle. In the case of wind interaction, the wind speed is higher towards the higher parts of the atmosphere due to less friction while it is low close to the earth surface due to the presence of people, trees etc. So, they are not tapped efficiently in termite mounds because they are only few meters high. As a result, induced flow doesn't operate in termite mounds.

2.3 Understanding Eastgate's Construction Techniques

The Eastgate comprises of 2 massive but narrow office blocks running East to West which are 9 stories tall and the city streets run down the middle, as does a 2nd story open skywalk. A glass umbrella roof bridges the gap between the 2 blocks. The major external heat source being the solar gain through the glazing and also reflectance from ground, the Eastgate's North and South facades' glazing was limited to 25%. In-situ concrete in combination with double-thickness walls on the exterior are used to moderate the extreme temperature fluctuations. Also, light-colored finishes are used to reduce heat absorption. Semi-arch hoods projecting over windows made of precast concrete provide sufficient shading. The street finishes as well as the office interiors are pale so as to reflect natural light.

- Moderating Internal Heat Sources: Artificial lighting being the main constant source of internal heat was a cause for concern. The exposed structural concrete elements of the offices are a major design feature as it helps to increase surface area thereby giving the building structure further capacity to absorb heat from rooms. Also, the concrete slab soffits absorb most of the heat emitted by fluorescent uplighters. Therefore, almost none of the heat from the lights enters the occupied space. Decision of choosing natural or forced ventilation was a major problem as natural ventilation would lead to noise and dust pollution due to opening of windows while forced ventilation would imply increase in running costs. The design approach that was chosen consisted of a pattern of air shafts and air voids which would allow the cool air to enter at the building's base and the warm air to discharge at roof level. The building would be cooled by the flow of cool night-time air. Fans would draw fresh air into the plant-rooms at a mezzanine level of about 10m from ground floor in the covered street which has cleaner air than surrounding main roads. The air passes to the offices via filters in the plant-room and is thereby directed through a network of masonry ducts in the central spine of each wing. Air would pass through the voided concrete floors and enter the office spaces through low level grilles located under each external window. The office ceilings consist of vaulted soffits as well as short protrusions to increase surface area and also to create a turbulent flow in the supply stream. Since the concrete is at a fairly constant 20 degree Celsius, the heat exchange cools incoming air in the Summer and warms it during the Winter.

Fig – 4: Extended Overhangs providing ample shade
Source: The Arup Journal, Volume: 32 | January - 1997

- Winter Heating: Occupants can turn on individual electric room heaters. Power is switched automatically on a half-hour cycle alternately between north and south wings so that overall consumption and peak demand are reduced. Only the low volume fans operate whilst the heaters are on, thus limiting the energy required to heat incoming air. A time switch to heater power is overridden by a thermostat which prevents operation above a predetermined ambient temperature.

- Shops: There is a public food court and retail units on the first floor as well as remaining retail units on the ground floor. Mechanical elevation is able to provide sufficient comfort but tenants are allowed to install air-conditioning if required. Exterior walls and front of shops are shaded with extended overhangs so as to limit solar penetration. Permanently open grilles allow night-time ventilation. Lights are installed in a false ceiling which consists of manufactured slots so that the heat generated doesn't enter the occupied spaces and instead enters the ceiling plenum. Heat extraction fans controlled by the tenants remove the heated air from the ceiling plenum to the outside of the Eastgate. They are left on during summer nights and turned off during winter nights.

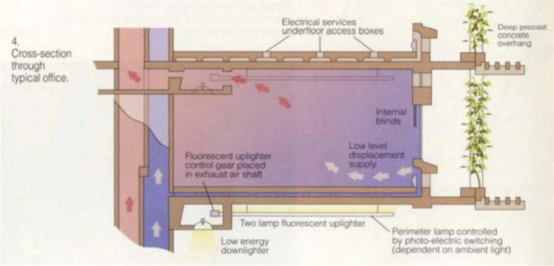

Fig - 5: Pictorial representation of cross-section of office space
Source: The Arup Journal, Volume: 32 | January - 1997

- Covered Pavement: Its major functions are to provide a sheltered shopping area in the base of the office blocks as well as to provide solar shading to the internal office facades. Also, it prevents heat build-up of the warm air from rising from the atrium below. There is about 800m^2 of open space between the 2 office blocks, enables the warm air from the atrium to rise along its edges by a process known as natural stack effect. The ends of the atrium are protected from rain by waterproof louvre enclosures. These also allow ventilation. The atrium provides strong natural ventilation by utilising the combination of a glass canopy and louvred ends. The atrium is maintained at normal ambient outdoor temperatures due to the large air change rates which prevents additional heat generation. Also, all the office windows consist of light-coloured venetian blinds. This helps to reduce the internal temperatures and absorbs sound thereby improving the overall acoustics of the rooms.

Fig - 6: The covered street with the suspended sky walk
Source: The Arup Journal, Volume: 32 | January - 1997

- Extracting the Heat: Daytime ventilation of about 2X air changes per hour in the occupied space is provided by the use of low-volume fans. This meets occupants' minimum fresh air requirements. The lower daytime air change rate reduces the impact of high outside daytime temperatures and thereby extends the storage period of the night-time cooling energy in the building structure. By thus varying the supply air quantity, the computer model predicted a 1°c reduction in daytime peak internal temperature. Other advantages were assessed against the additional capital cost of the low flow rate fans, including:
  - restricting larger energy consumption fans to night-time when electricity is cheaper (and lower maximum demand).
  - reducing the cost of sound attenuation for the supply fans because the large volume flow rate fans will generally be working when the building is empty
  - reducing airspeed through the supply air grilles during the day, thus encouraging displacement ventilation in the offices (enhanced by maximizing floor-to-ceiling heights within architectural constraints).

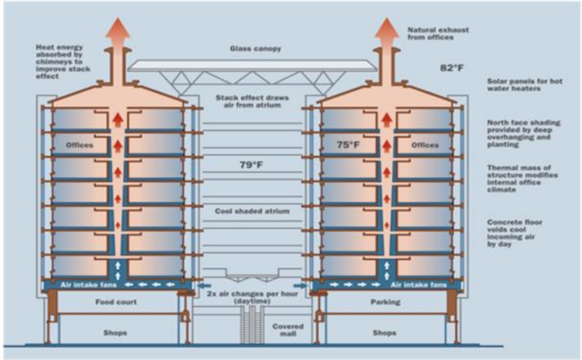

Fig - 7: Pictorial representation of heat extraction
Source: The Arup Journal, Volume: 32 | January - 1997

3. ENERGY CONSUMPTION

Actual energy consumption readings were available after the first six months of building operation. The energy consumption of shopping malls and food courts was ignored. This was done to make a direct comparison between Eastgate and similar air-conditioned buildings. It was carried out by deducting the sub-meter readings. The results are very favorable showing that Eastgate has a power consumption of 9.1 kWh/m^2 compared with a sample of six other Harare developments ranging from 11kWh/m^2 to 18.9kWh/m^2, and thus an energy consumption per unit area of 48%- 83% of other typical CBD air-conditioned buildings. Due to its uniqueness, it is difficult to compare Eastgate with other buildings in Zimbabwe based on peak demand because of the presence of additional features like extensive shopping areas with feature lighting, shopping mall lights, food court cooking appliances, and ventilation fans, escalators, etc. However, a comparison of peak demand meter readings to date suggests that Eastgate has a maximum demand per unit 10% lower than the average for six other buildings considered.

4. CONCLUSIONS

Eastgate is a unique and marvelous building not only in Zimbabwe but in the region as well. There are very few passive-cooling buildings with such sophistication. As this is highly innovative and was being undertaken in Zimbabwe for the first time, it required considerable originality in its design approach. The results of the preliminary climate measures show that the office environment is close to expected comfort levels. The early available data indicate that there would be a saving in running and maintenance costs. The reduced energy requirements as well as the use of simple mechanical plants, namely fans ensured less expensive spare parts and a running cost which is comparable to a similar air-conditioned building. The reduced energy demands and non-reliance on air-conditioning have significant positive environmental impacts. The aesthetics of the buildings are in such a way that it enhances its required function without being pale and bland. This ensures that the Eastgate stands on its own and is unique in its own way. Biomimicry is therefore a great tool to spark the human mind to look in detail and find solutions from mother nature.

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