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Ventilation in Termite Mound : New Solution for Follow in Architecture

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Abstract: The airflow in building environment is a strategy that could provide indoor thermal comfort conditions in warm and dry environment. Therefore, formation of ventilation inside buildings is essential. In the meantime, the nature has some structures, which have created much potential in the natural ventilation. Thus, this research aims to provide a mechanism for improving natural ventilation in the building to recognize the effective features in the termite mound, as a successful natural structure in hot and dry climate. In order to conduct this research, extensive examples of termite mounds were studied, which were located in the hot and dry climate. The research tool was the library studies carried out so far in the field of biology, which provide strategies to promote natural ventilation system in the building after recognizing the process of termite mound ventilation and its effective factors. The results indicate that wind, water, temperature differences, and the form of inner channels of the mound have an important role in natural ventilation. These factors require vertical ducts inside the building in order to streamline the air. However, other features such as the materials applied in the termite mound and placing in the ground reduce the heat dissipation inside mound building, but these features have no effect on the process of natural ventilation inside the mound.
Keywords: Ventilation, Termite mound, Follow the living structures, Biomimicry, Air Exchanger

I.Introduction

Effective use of natural ventilation is a viablestrategyto achieve energy-efficient buildings,but thisstrategy is difficult to master because the air intake and discharge may be more or less than what is really needed [1]. Thus, providing adequate natural ventilation solutions for buildings requires further study on successful examples. Many of such examples can be found in the form of natural phenomena. Regardless of field of activity, nature has always been a reliable and rich source of inspiration for scientists and engineers. Every living being maintains a unique balance with its environment, and continues to reproduce and survive by exercising effective actionsin response for its needs; actions that have been developed and sometimes perfected through recurring tests of survival undergone by countless generations of the living being [2].

Termite mounds are stable natural structures found in desert areas andhave fascinatedresearchers for more than two centuries [3].One source of this fascination is the adaptability of termite mounds with their environment throughout different seasons, which is achieved withminimum energy consumption and only on account of good architectural design of structure.

This study seeks to employ thefeatures of termite mound as a not able example of efficient natural ventilation [4] , which In the case of termite mound, is associated with two important needs of the inhabitants, namely thermal regulation and gas exchange in ahot climate [5, 6, 7].

Although some previous buildings have been successful in taking inspiration from the ventilation of termite mounds to reduce energy consumption, research shows a significant difference between the results of these buildings and those of termite mound structure [8]. Hence, further study of termite mounds can still contribute to understanding the process of ventilation within these mounds and adopting the desirable features in the architecture of human structures. The basic questions that are raised in this regard and this study seeks to answer are:

How natural ventilation within the mound addresses the needs of termites?

What is the role of channel morphology within the mound in thegas exchange process?

What is the effect of outside wind and temperature on the quality of natural ventilation in the termite mound?

Internal structures of termite mounds appear to have unique features that worth to be mimickedin natural ventilation of human architecture. To determine these features, we first briefly review the variety of termite mounds, and then provide an architectural analysis based on existing findings and observations.

II. Material and Methodology

Biomimicry is to take inspiration from natural structures to find new solutionsforhuman problems, including those in regard to architecture [9]. Following this approach could be difficult however, as it requires meticulous study of natural phenomena to deduce their governing principles [10].

So far, several varieties of termite mound have been identified.In terms of internal structure and mechanism of ventilation, mounds are divided into two categories: capped chimney mounds (operating based on thermosiphon flow) and open chimney mounds (operating based on induced flow) [11, 12, 13].In terms of general morphology, termite nests are divided into severalcategories: epigeal (above surface), subterranean and arboreal[14, 15].As a general assumption, termite nest need to be able to discharge the air polluted due to physiological and food processing activities of the colony [16, 17, 18].Likewise, natural ventilation is also necessary for discharging the heat generated due to colony metabolism [19, 16, 17, 20, 21, 22, 23]. In the studies where the effect of natural ventilation mechanism on thermal regulation and gas exchange have been investigated by measuring the temperature, humidity and carbon dioxide within the termite mound, it has been found that outsidewind and temperature both have significant impacts on natural ventilation [6, 12].In another group of studies, where the internal structures of termite mounds have been analyzed and compared with lung structures, it has been reported that the morphology ofthese structures have a decisiveeffect on themound ventilation[8, 24].

Although termite mounds have been the subject of many studies,most of these studies are in the field of biology [25, 15, 7, 11, 16, 26], and those witharchitectural perspectiveshavegenerally analyzed the mounds' internal ventilation[13, 4, 27, 28, 29, 30], and a detailed description of mechanism ofventilation and the factors affecting the gas exchange process within the moundis yet to be provided. Also, these studies lack the architectural perspectiverequired to infer specific principles to instill inspiration or be mimicked byarchitects and civil engineers.

Therefore, examination of termite mound as a natural structure could revealviable natural ventilation concepts and thereby leadto formation of novel architectural solutions.In other words, this study seeks to examine the ventilation process in termite mound from a purely architectural perspective.

This study provides an architectural analysis of termite mound with focus on the concept of natural ventilation to identify explicit elements influencing the mound ventilation process andincorporate them into passive architectural solutions.Research subject is the termite moundsfrequently found in hot and dry climates, whose structural morphology provides a potential for creation ofinternal natural air flow. The research tool comprises the existing biology studies.After studying the various morphologies of termite mound, the shared features of thesemoundsare used as the basis for the studyof their internal ventilation.The factors influencing the mound ventilation are then subjected to a thermodynamic analysis, and are subsequentlyexpressed with graphical representations.The researchers attempt to compensate for research limitations such as lack of physical access to termite mound, and lack of access tobiology laboratories anddigital fabrication workshops bybroader investigation of biology studies and their findings and more carefulexaminationof the mound's internal processesin thermodynamic analysis.

III.Results

Thenestof a termite species called MacrotermesBellicosuscan be as height as 3-4 metersand houseabout two million termites, which would live, work and breathe within this structure.The amount of oxygen to be consumed in such structure is thus significant, and absence of ventilation can lead to suffocation of all inhabitants within 12 hours [4].Thus, how this nest can be ventilated without any visibleopening on the exterior?

Termites have to build their mounds such that temperature, humidity, and carbon dioxide levels (due to their metabolism) would be controllable [22, 31].These goals are achievedin part by active efforts of termites [14],but majorly by passivefeatures ofthe nest architecture,and most importantlyits natural ventilation [16].

Natural ventilation of termite mound has two tasks;firstly to discharge the stale air and draw fresh air into the mound [6], and secondly toexhaust the hot air and draw the cool breeze into the nest [7]. As such, natural ventilation is essential for the function of the mound, and itself is shaped by several factors.In general, natural ventilation can be explained in three stages:

1- Draw of fresh air from the outside into the building
2- Passage of air throughout the interior spaces to provide fresh air and push away the undesirable heat and pollutants on its path.
3- Exhaust of air to the outside environment [32].

Next, we examine these three specific stages in ventilation of a termite mound.

1.Draw of fresh air

Wind: Draw of fresh air into termite mound is largelyfacilitated by the wind.Research has shown that the presence of small pores on the mound walls plays the primary role in this respect.One of the clear differences between the buildings inspired by the mound design and the actual termite mound is the inability of these buildings to exploit the wind,as a primary source of energy,for their own function [8].

But given the uncertain and shifting nature of the wind,relying solelyon natural winds tocarry fresh air via a certain opening is not a sensible strategy. The mentioned uncertainty means that the likelihood of a wind blowing at desirable times and with desirable speed and from a desirable direction is low.So any designcounting on directing wind via a certain space will not have much reliability.

One way to createair flow in a space is to create a pressure difference between two of its points (also known as Ventury flow).This pressure difference can be due to differences in air flow rate at different places (Klayven, 2010).This is interesting in the sense that natural surface air flow, i.e. wind speed, typically increases with the height.

In atermite mound, this effect is used to facilitate airflow, and is strengthened by the increased height difference between wind inlet and outlet points.The same effect can also be used more purposefully and much more efficiently in high-rise buildings,because while termite mounds using this effectrarely rise above theheight of 2-3 meters,high-rise buildings are at least 30 meters high[8, 33, 6, 34, 35].

In a typical termite mound, large vertical chimneys rising above the near ground openings create a negative pressure at the mouth of these shafts (Figure 1).As a result, Venturi flow inducesthe fresh air into the mound, throughthe nest, and out of the chimney. Unlikethermosiphon-circulationmodel,induced flow modelis based ona unidirectional and oscillatory flow [6].Table 1 shows the wind speed at three differentpoints on the mound wall.The airflow in the mound channels depends on the wind energy and thegeometrical complicity ofthe nest galleries and chambers [22, p. 128].

Wind speed(mean)(m/s^2)	Altitude from Ground (meter)
0.72(0.42)	0.5
1.38(0.64)	1.5
1.90(0.62)	2.5

Table 1: wind speed measured over a year (mean) [6]

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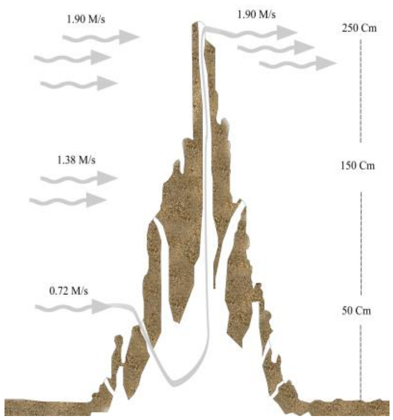

Figure 1: pressure difference between air inlet and outlet

As shown in Figure 1,wind has a substantial impact on the network of channels within the mound.Wind creates a pressure differenceover the mound surfaces, which inducesairflow in the channelsviathe pores on the walls [6].In most cases, wind exerts a suction force at top of the mound and this force inducesan upward airflow from the nest toward the chimney [36].

Groundwater: water is another essential need of termites. The thin and delicate skin of termites means that they need relatively great amounts of water to maintain their metabolism.In a typical termite nest, the average moisture content is between 89 to 99 percent. Termites also need some waterfor drinking and making the mortar required for their nest.In arid and desert terrains,termites may have to dig very deep to reach an underground aquifer [4, p. 168].In times of extreme heat, termites move the moist soils (wetted by proximity to groundwater) to the mouth of air inlets to create airflow without upsetting the water vapor or carbon dioxide levels[22, p. 129, 26], which is whythey need to build their mounds in the proximity of underground waters. A study on the nest of an African termite species called Barossa has shown that theydig tunnels as deep as 10 meters to reach the underground water. Theythen utilize evaporative cooling in a way that temperature fluctuations inside their nest never exceeds 1°C, even in the hottest season(Figure 2) [37, p. 91].

Thus, the contact of inflowing air with moisture in the subterraneanchannels cools and wets the air to be passing across the mound [22], thereby cooling the entire nest.

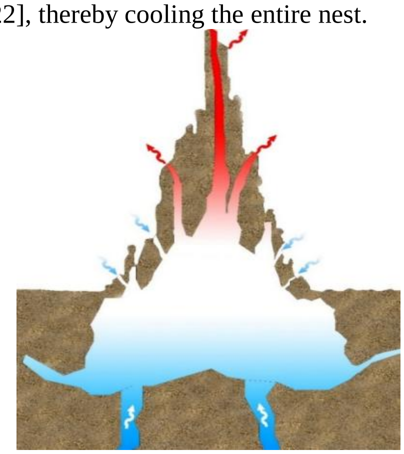

Figure 2: paths of air infiltration into the mound

2.Passage of air throughout the interior spaces

Complex internal structure of the mound:regardless of the source, whenair flowsinto the mound,morphologic features and interconnection of its channelsallow the flowto circulate throughout the entire mound.In terms of morphology and size, channels within the termite mound can be generally categorized into three networks: 1-the network of large-diameter undergroundtunnels spun around the main nest and connected to the nest via a series ofsub-channels. 2- The network of upper tunnels that connect the lower section to the upper chimney. 3- The network of surface tunnels around the mound, which areconnected to bothof the mentioned networks via complex structures.This network consists ofnarrow tunnels ofabout 2-3 mm in diameter, which is connected to the outside surface.Together, these three networks provide the structure necessary to facilitate airflow throughout the entiremound (Figure 3) [4, 25, 12, 8, 24].

Figure 3: Internal air channels of a typical termite mound: a)external tunnels; b)deep internaltunnels; c)subterranean tunnels; d) horizontal cross-section of the mound at the height of 1 meter above the ground; e)horizontal cross-section of thenest and the base of the central chimney [8].

Metabolism of organisms:fermentation in fungus combs produces heat and warms the nest.The sheer number of termites living in the nest also increases the nest temperature. The resulting hot air goes up and then into the ducts extended across the walls.Interior and exterior surfaces of these walls are quite porousand allow the inside carbon dioxide to be exchanged with the outside oxygen[4, p. 166, 11].

2.1Exhaust of air:

Temperature difference:Temperature is the most important reasonbehindair density variations in the mound. This can lead toair density differences andincreasednaturalheat transferwithin thisstructure.It is not theheat generated by the metabolism of termites and the inflowing wind but ratherthe temperature difference thatplays the primary role in natural heat transferwithin the structure [6].In placed that are extremely heated by intense sunlight during the day,heat flow creates an upward or downward wind flow [38, 39].The presence of an opening at the top of the mound creates a suction force from within the mound towards the outlet (Figure 4).Also, the mound shape allows a part of its surface to be shaded by another part that is intensely heated by sunlight, and the resulting temperature difference inducesairflow inthe wall interior.

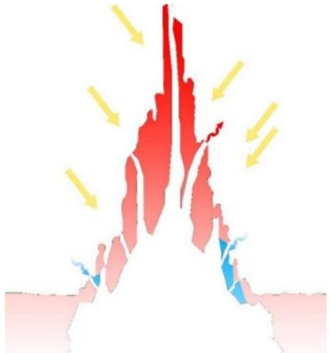

Figure 4: Diagram of mound walls on a hot summer day

3.Following the termite mound for improved natural indoor ventilation

The mound building inferred from the features identified in the reviewed studies,after modified according to functional and spaces requirements, is shown in Figure 5.As shown in Figures 5 and 6,the best way to induce natural ventilation is to create a vertical space in the form of continues ducts extendedup to the roof. As seen in termite mounds, such spacewill allow the flow to be sucked from the roof after beingcooled in the basement.With such solution, the shell of residential and commercial buildingscan be utilized to meet otherrequirements such as lighting and view.

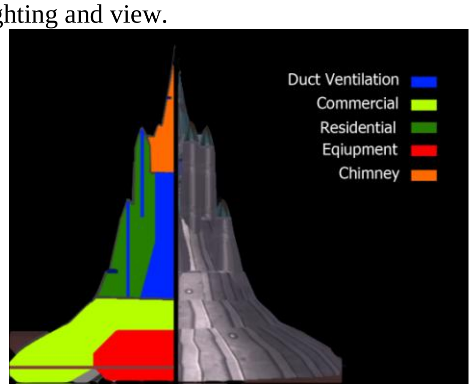

Figure 5: functions of the mound building based on the natural ventilation features

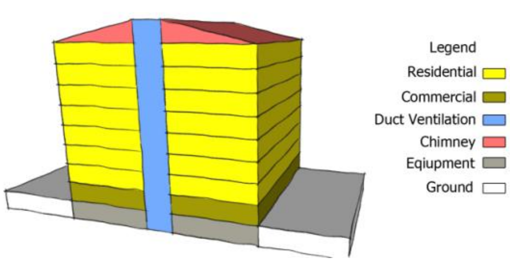

Figure 6: natural ventilation solution mimicked from the termite mound structure

IV.Discussion and conclusion:

In general, airflow within a termite mound is due to several factors:

1- The metabolism of organisms living inside the nest produces considerable heat, which in turn leads to airflow fromsome parts of the nest toward the cooler base.

2- Multiple air vents extended over the vertical surface of the mound let theseasonal winds in and then across its structure (Figure 1).

3- The mound is often rooted well within the ground to provide accesstogroundwater, which is usedforevaporative cooling of the incoming air (Figure 2).

4- Exposure of the central chimney to direct sunlight creates an upward air suction, which facilitates ventilation (Figure 4).

5- Mound channels have two distinct morphologies:i)narrow morphology to suck the fluid into the main channels by capillary action; ii) broad morphology to facilitate air flow.Thus, extreme endsof all channelshave a narrowing form (Figure 3).

6- The principal factorobserved in the mound is air circulation and suction from multiple points, which allows adequate ventilation of the nest.

Beingpartly below the ground surfaceallows the mound to prevent heat loss to the outside environment,and yet, has no impact on the air ventilation within the structure.As the review of studies showed, mechanism of ventilation in the mound is formed by several factors.In the ventilation process,first, pressure difference due to difference in wind speed of upper and lower sections draws the fresh air into the mound.On hot days,incoming fresh air is cooled by groundwater, and then cool fresh air passes through the channels extended across the mound structure.During this stage, airflow will be affected by the particular morphology of different tunnels.Finally, the stale air will be exhausted by thesuction force created at the top of the mound due to temperature difference.

The best approach to mimicry of thermal mound for architectural purposes is to consider,at the center of the structure, a series of vertical ducts that would be connected at one end to the underground cooling space and at the other end to the air suction space on the roof.Optimization of cross-section of these ducts and determination ofexact mechanism of their connection with individualindoor spaces of residential and commercial units can be worthy subjects for future research into such ventilation system.

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