Biomimetics
Assignment 2
Cooperative behaviour in animals inspiring HVAC principles in eco-building design

10198
Mechanical Engineering with Advanced Design and Innovation
University of Bath

Personal Tutor: Dr. Marcelle McManus
Word Count: 2986

SUMMARY

Animals that exhibit cooperative behaviour are capable of building homes that exhibit highly specialised thermal engineering techniques, and these have started to inspire HVAC principles for eco-building design. Designs in this field are rare, but do exist and are based on either the sociable weaver bird nest or the termite mound.

Engineering solutions can be split into two categories; buildings that self-heat (consisting of the Kungsbrohuset offices, the Mall of America and a house built by Georgia Tech) and buildings that self-cool/ventilate (consisting of the Eastgate Centre and Council House 2). All of these buildings save energy when compared to traditional designs; the Kungbrohuset, Mall of America and Georgia Tech buildings have energy savings of 25%, 20% and 50% respectively. Meanwhile, the Eastgate Centre uses 10% of the energy a similar sized building would consume, while CH2 reduces electricity and gas consumption by 85% and 87% respectively when compared to its predecessor.

After evaluating the evidence available, this review finds that passive solar power is the most efficient method for heating a building, while buildings based on the design of termite mounds are much more efficient at cooling and ventilating than traditional methods.

TABLE OF CONTENTS

1. INTRODUCTION

None of us, including me, ever do great things. But we can all do small things, with great love, and together we can do something wonderful." – Mother Teresa

Nature has a reputation for being challenging, unpredictable and unforgiving, and as such poses a number of problems for the wildlife that live in it. While some species such as tigers and bears live individually, the majority of animals ensure their survival by working together. This cooperative behaviour ends up providing food, security and comfort.

But how does this relate to engineering?

It is known that animals are capable of building some of the most complicated yet efficient homes in nature, and these usually contain engineering principles that more effective than what is currently used by mankind. Often, these structures have HVAC principles (heating, ventilation and air-conditioning) built into their design, making them highly efficient in their respective environments. Examples include termites building mounds that can cool the inner temperature of the structure using external air, and the sociable weaver bird designing nests that can expend excess heat during the day but retain it at night. These characteristics have long fascinated engineers and architects, but it is only recently that the temperature regulation abilities that animal nests provide have been incorporated into building design.

The aim of this literature review is to assess the current bio-inspired building designs, as well as critically reviewing the effectiveness of the functions that they contain. Specifically, it looks at the homes that animals (such as termites and birds) reside in and how their defining qualities have been recreated by engineers and architects in their building designs. It will contain an initial review that describes and classifies the current solutions, and a discussion that critically appraises and compares the strengths and weaknesses of work in the area.

2. REVIEW OF ENGINEERING SOLUTIONS

When considering eco-buildings that have been inspired by natural designs, they can be split into two categories. The first is *architectural*, which takes inspiration from what natural structures *look* like, while the second is *functional*, which takes inspiration from the unique *functions* that these structures possess and perform. For the purposes of this report, only eco-buildings inspired by functional design characteristics in nature will be considered.

Thermal functions can be split into three groups known as collectively as HVAC; *heating* (which focuses on how to heat a building using the environment), *ventilation* (which focuses on providing fresh air to a building while removing the stale air), and *air-conditioning* (which focuses on cooling a building using only the environment). However, because the literature explored found buildings that exhibited ventilation and air-conditioning principles together, the sub-stream that will be reviewed is a category called *cooling*. This is shown in **Figure 1.**

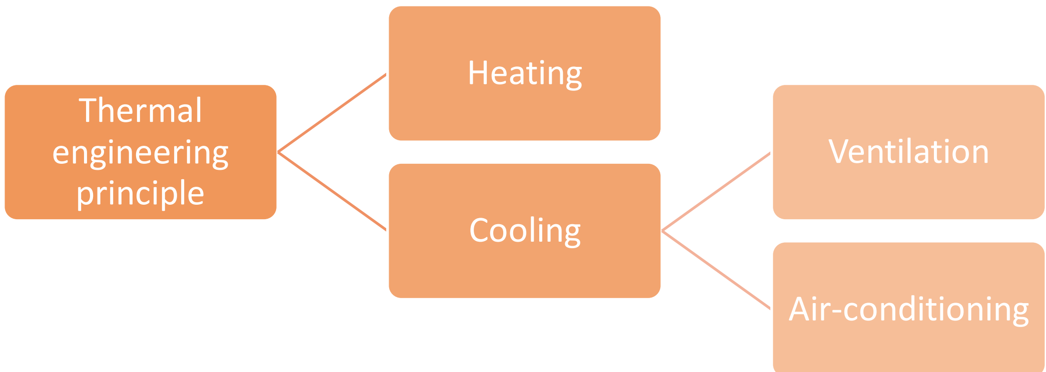

Figure 1: Classification of the eco-building solutions categorised by the thermal engineering principle they aim to optimise.

A. HEATING

The nest of the sociable weaver is an example of a natural self-heating home. Prevalent in Southern Africa, these birds have the ability to construct large communal nests that can adapt to the harsh climates found in areas such as the Kalahari Desert (temperatures ranging from 33°C to -7°C). They do this by constructing their nest using three types of material; large twigs and stems which create the basic shape of the nest, dry grasses that form individual inner chambers that the birds live in, and soft materials like feathers that line the inside of these chambers. [1] This lining does not allow any heat to escape; therefore at night, the inner chambers are warmed using a combination of the heat trapped from the environment during the day (a bit like a greenhouse) and the body heat of the birds that sleep in them. [2]

Stockholm Central Station uses this method to help warm a nearby office building. Sweden's busiest station with over 200,000 daily visitors, engineers have designed systems that use the excess heat that humans give off to provide heating. This is a big source of energy; indeed, a human dissipates as much energy in an hour as a 100W bulb does in the same time period. [15] Heat exchangers are built into the roof of the station to capture the rising, excess heat that people generate and transfer it to water. This water is then transferred using a series of pipes to the thirteen floor Kungsbrohuset office, providing it with approximately 10% of the total energy needed to warm the building. [3] Although only a small proportion, this design has lowered the overall energy costs of the building by 25%. [4]

The other element of the sociable weavers nest design is passive solar power. This converts sunlight into usable heat without using mechanical devices, and is being increasingly used in privately built eco-buildings. In 2007, Georgia Tech were able to create a house that used these principles to heat it in the winter, but cool it in the summer. In the winter, radiation from the sun comes in through the windows and strikes the floor, which absorbs some of this energy to use for later. However, some is reflected back into the room, and this radiation (now been converted to heat energy) is not allowed to leave the room due to the insulated design of the house. In the summer, the sun is higher up in the sky, and so a smaller amount of radiation passes through the windows (meaning an even smaller amount is converted to heat). Instead, the oak roof absorbs the majority of the heat – but is designed in such a way that none of it is transferred to the main house. Heating using passive solar power is much more effective than using body heat; this is due to both the energy emitted by the sun being much greater than that of a human, and the increased efficiency of the process (estimated at about 60-75% during the summer). Designs like this can save up to 50% of energy costs. [5]

The Mall of America uses both principles in conjunction with one another. Like the Georgia Tech design, it is partially heated using passive solar power (in this case, 1.2 miles of skylights in the roof of the building, see **Figure 2**) but it also makes use of the excess body heat people give off using techniques similar to what is used to warm the Kungsbrohuset offices. It also uses a third heating source; the excess heat given off by the light fittings inside the mall – and all three of these combine to ensure that the temperature of the mall is a constant 70°F.

However, on winter days when the sun is low in the sky and the number of customers is lower, a possible heating problem arises. To solve this, the mall also has air-conditioning system installed. These systems allow the operator to control the humidity – and as humidity is more important than actual temperature when it comes to the perceived heat of a room, this can effectively act as a heating system in the rare instances that it is required.

Combining these three principles does save the mall money, but it is not as much as a building that solely uses passive solar powered heating. Overall, the reduction in energy costs is around 20%. [6]

Figure 2: *Image showing one of the skylights present at the Mall of America in Minnesota. There are over 1.2 miles of these in the building.* [7]

B. COOLING

The termite mound is an example of a naturally cooling home. Common in Africa, Australia and South America, termites have the ability to construct large, communal mounds that can maintain a constant internal temperature despite fluctuating external temperatures. An intricate network of passages leads to a central chimney, which gathers the hot, stale air generated from the millions of termites and fungi within the mound. Unlike a typical chimney however, this is sealed at the top, meaning that hot air cannot escape. Instead, this air is cooled using fresh air blowing against the mound. It is forced through small, porous holes in the outer walls and travels through the smaller tunnels until it reaches the central chimney and mixes with the hotter air there. At the same time, the fresh air blowing against the mound also generates a suction force on the opposite side, which pulls hot air out of the main chimney. [8] This creates an internal air current that ventilates/cools the entire mound.

The Eastgate Centre in Zimbabwe was inspired directly by this system. A large chimney exists in the centre of the building, and this gathers all of the heat generated by people, electronic equipment and heating systems. At the bottom of the building, a series of 32 low and high volume fans suck fresh air from the outside, which is forced to the centre of the building through a network of ducts found on each floor. This cools the hot air down in the same way as the termite mound does – allowing heat transfer through convection. [10] Hot air is also removed, but slightly differently; instead of this air being removed using suction forces, the chimney at the top flows into 48 brick funnels that are open to the sky. From here, the hot air simply rises out of the building. This system cools the building down as effectively as an air-conditioning unit – but because these are costly and energy hungry, not using these systems mean the building uses only 10% of the energy a similarly sized building would require. [9]

The Council House 2 (CH2) building in Melbourne also uses this principle with a few tweaks. As the north facing chimney stacks receive more sun, these were painted black in order to encourage more warm air to rise out of them. The main chimney also was moved from the centre of the building to the side as it was more effective in this position in the new design, as well as fresh air only being gathered on one side of the building instead of two. These modifications meant that 100% fresh air was supplied to all occupants, with one complete air change every half hour. When compared to the existing Council House, it was able to reduce electricity and gas consumption by 85% and 87% respectively, as well as producing only 13% of the emissions. [10][11] Even when compared to similarly sized buildings with a Five Green Star rating, it had emissions that were 64% lower – which led to it being the first Australian building to achieve a Six Green Star rating.

3. DISCUSSION

The buildings that have been presented so far have strengths and weaknesses in their design which directly influence their efficiency, and this section aims to discuss these. However, as the two types of building discussed in the review have different aims (heating/cooling), they cannot be compared directly. Instead, the buildings in each sub-category will be compared to each other.

A. HEATING

Three buildings were found that used principles commonly found in the nests of the sociable weaver. These were the Kungsbrohuset offices, which use the body heat from people in a nearby station to partially heat it; the Georgia Tech house, which uses passive solar powered heating as an alternative to gas central heating, and the Mall of America, which combines the two as well as using the excess heat from the various light fittings installed inside the building.

The three buildings discussed have differing energy saving cost percentages; 25% for pure body heat, 50% for passive solar power and 20% for the combination. While it makes perfect sense that passive solar power would save the most due to the immense energy that the sun provides, it was surprising that the Mall of America that uses both passive power and body heat saved less than a purely passive building. This is due to a few reasons; firstly, the space that needs to be heated up is much larger than the Georgia Tech house (452,000m^2 against 51m^2). The Mall is also inefficient in both areas when compared to other buildings; it can't generate as much heat through people as it has less people in comparison to the station (40M annually against 73M), while it doesn't covert as much of the suns energy as the Georgia Tech house (60% against a maximum of 75%). Adding to this, the Mall has other energy sources; air-conditioning is used to cool or provide extra heat to maintain the constant 70°F temperature if required, while some stores do have conventional heating systems within.

The energy saving cost percentages also clearly show that using body heat alone is not an effective way to heat a building. Both examples that use this method do not use this as a sole heating system, but employ other techniques alongside it. The Mall uses two other heating methods, while the Kungsbrohuset offices use traditional heating for the remaining 90% of the heat that it needs. While this technique is fantastic for weaver birds in nature, it is unrealistic to use in real life due to the large numbers of people (only found consistently in airports and stations) needed to solely warm a small space, and the close proximity needed of the heated building to these locations.

B. COOLING

Both buildings reviewed were designed by the same architect (Mick Pearce), and are based on the same design principle – the natural cooling systems that termites employ are much more efficient than traditional air-conditioning methods. This was proved correct with reductions in both emissions (87% for CH2) and energy (90% for the Eastgate Centre).

These buildings do have differences. As CH2 is smaller than the Eastgate Centre (12,500m^2 against 31,500m^2) less heat is generated and hence needs to be removed from the building. The result of this is a smaller amount of fans and a chimney that is situated in the corner – however, this is also because CH2 is located in a cramped city spot, where building space is at a premium (especially in Melbourne). This reduces the amount of heat that can be removed using only this technique, and as a result CH2 also uses water to cool it down. On the other hand, the Eastgate Centre takes a block of space, and can maximise its efficiency by collecting the air that hits it from all directions.

The Eastgate Centre does have its weaknesses though. The biggest is that its internal temperatures can still peak at 26^{0}C (**Figure 3**). This is caused by unpredictable temperature swings outside and the relatively slow reaction times of the building. And has led to further research into a control system that could adapt to the external conditions, as well as on a concrete floor design that can optimise heat transfer. [12]

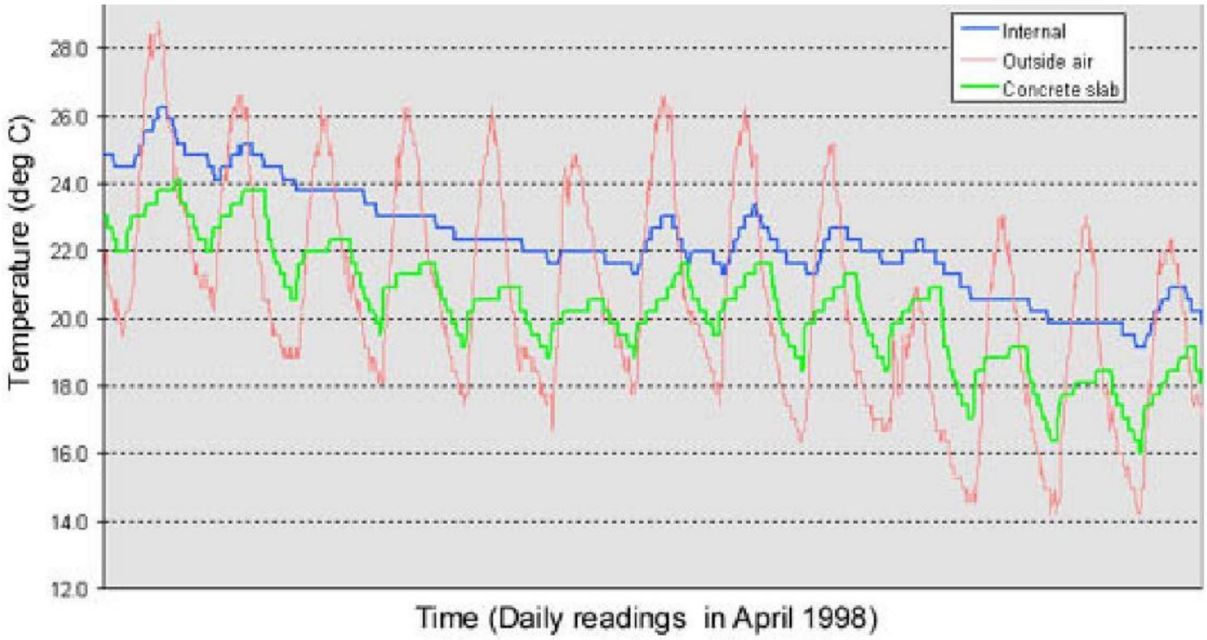

Figure 3: *Temperature-time plot that shows the average internal, outside air and concrete slab temperatures during April 1998.* [8]

While the buildings work on the principle that termites employ in their mounds, these principles have recently been proven untrue. New models say that termite mounds act like lungs, and have three sections; an area where air moves via convection, an area in which the air is still and moves via diffusion, and a hybrid area in which both convection and diffusion occur. [13][14] While the buildings designed by Pearce are very effective in reducing energy and emission costs, incorporating this updated theory into new designs could decrease costs further in the future. However, the current level of expertise available might make this difficult to achieve.

4. CONCLUSION

Animals that exhibit cooperative behaviour are capable of building homes that exhibit highly specialised thermal engineering techniques, and as such these have started to inspire HVAC principles for eco-building design.

The sociable weaver bird nest has two qualities that make it unique; an ability to capture the heat of the sun using passive solar power design theories, and the use of body heat to keep certain sections of their nest warm at night. This has inspired larger eco-buildings such as the Kungsbrohuset offices and the Mall of America. While no mainstream building has been built that can be heated solely using passive solar power yet, privately built houses such as the one designed by Georgia Tech have shown that this technique can be also used to keep small homes warm. These designs were able to cut energy costs by 25%, 20% and 50% respectively.

Only two buildings were found that could actively cool via non-mechanical means, and both of these were based on the same architect's idea of using the cooling of a termite mound as inspiration. Pearce first designed the Eastgate Centre which only used 10% of the energy a similar sized building would consume, before tweaking his design and creating the Council House 2 (CH2) building in Melbourne ten years later, which had emissions 64% lower than one with a Five Green Star rating.

Passive solar heating was found to be the most efficient method of warming a building due to the large amount of energy this method absorbs (75%). It also found that using body heat was an ineffective way to solely heat a building, simply due to the massive amounts of people that would be required to produce anywhere near the amount of energy required. While the designs of the Eastgate and CH2 buildings reduce the amount of energy and emissions considerably when compared to structures of the same size, these designs were based on an incorrect model of the termite mound. An updated building might be able to deliver even greater energy savings, but it is hard to see this being implemented in the near future.

While eco-buildings are growing in popularity due to a combination of reward and regulation, the size of the bio-inspired section is still relatively small. Indeed, with the exception of CH2, there have been no new large bio-inspired buildings built this millennium that use non-mechanical heating or cooling techniques – meaning that only five structures could be analysed in this literature review. The majority of countries in which these buildings currently reside either have extremes in weather or expensive energy. As this is not a problem in many countries, they have not taken steps to prevent it.

It seems that bio-inspired eco-buildings have already matured in the market which is unfortunate due to their excellent track record in reducing energy and emissions. Instead, eco-buildings of the future look to be focusing on mechanical solutions to increase energy efficiency, waste reduction and sustainable design.

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