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# "Study of Beehive and its potential "biomimicry" application on Capsule Hotels in Tokyo, Japan"

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## Abstract

The present research focuses on the biomimicry application of a beehive to Capsule Hotels in Tokyo. The motivation for this investigation is the similar thermal and ventilation requirements between humans and bee colonies as well as the similar typology of the bee combs and capsule rooms. The aim of the current research is to assess the effectiveness of biomimicry strategies based on the example of a beehive so as to provide thermal comfort and reduce the heating/cooling loads of capsule hotels. Laboratory testing and physical modeling indicated the air flow patterns within a beehive. Computer modeling using HTB2 indicated improved thermal comfort under natural ventilation conditions and reduced energy consumption under mixed mode ventilation where biomimicry alterations were incorporated into the capsule hotel design.

Keywords: Biomimicry, beehive, capsule hotels

### 1.0 Introduction

Tokyo is one of the metropolises of the contemporary world and one of the densest cities in matters of population. A high number of global corporations reside in the city centre and the majority of local citizens work there. Due to the demanding timetables, a high number of employees usually expand their working hours so as to satisfy the deadlines of the projects. As a consequence, many occupants do not afford time to return to their home, get rest and go back to work the next morning. The aim of the Capsule Hotels construction was to offer low cost accommodation for such employees.

As a construction concept, Capsule hotels are similar to bee combs. Combining the fact that the thermal and ventilation requirements for both men and bees are similar, it would be of interest to carry out biomimicry analysis of the beehive and its potential application on the capsule hotels. The aim of this research is to estimate the potential improvement of the energy consumption profile of such hotels while maintaining comfort to their clients through the biomimicry applications.

Biomimicry is a sector which the last twenty years started expanding in different fields of science. Its name derives from the words "bio" which means "life" and "mimic" which means "imitation" in Greek. Biomimicry in architecture actually gets inspired from the designing strategies, techniques or concepts that the living organisms adapt in order to serve their needs and secure their survival.

### 2.0 Literature Review

Honeybees seek a shelter within which to construct their combs, and have used the same comb pattern for thousands of years. This pattern satisfies their thermal and ventilation needs, secures the development of their offspring, storage of their food and offers accommodation for the colony. The preferable temperature inside the colony is around 34°C when raising brood and 17°C otherwise (Hooper 2010). Moreover, through the structure of their hives, bees achieve a ventilation rate of 50-60l per minute and relative humidity levels of about 45-55% (Shaw 2011).

In the current research the British National beehive will be examined. This beehive imitates the spacing between combs which honeybees would use in natural hives, but provides enough support that bees can create flat combs rather than curved. So as to clarify the biomimicry analysis and the possible applications on the capsule hotels, the elements will be considered as the structure, envelope, services and the interior.

Considering the beehive, the bee combs could be resembled as the interior and the structure at the same time. Bees construct their cells into hexagonal shape. In this way they achieve high wax savings in comparison with other patterns since each wax wall is also shared with the adjacent cells (Frisch 1983). Moreover, the hexagonal shape is more stable in vibrations of the moving bees and it is able to absorb them without collapsing (Asha 2010). Through personal investigation of a comb, an average worker bee cell has a ratio of width to length approximately 1:2 though this is not a standard rule. Moreover, honeybees re-use the wax from the abandoned hives in order to save time and effort for creating a new one (Frisch 1983).

As for the envelope, the British National beehive replicates the conditions of the beehives in nature. The distance between the frames is of two “bee-spaces” id est 12-16mm and the distance between the interior partitions of the hive and the frames is one “bee-space” (6-8mm) (Waring 2011). As for the services, bees prefer evaporative cooling in order to reduce high air temperatures inside the hive. They collect drops of water which are positioned in the hive, then the bees fan their wings to pass air of the drop so that the evaporation will achieve a decrease in the air temperature (Brackney 2009).

Considering the Capsule Hotels, the interior and their structure are based on readymade plastic furniture which consists of capsule beds. The beds can either be inserted in a metal frame structure or placed directly one above and next to another. The first capsules were of almost the size of a tatami mattress (90cm*180cm) and of 100cm height (Sowa 2000). However, more modern designs create a capsule of 120cm*234cm*110cm (Detail 2010). The main appliances provided inside the capsule are TV, radio, lights, alarm clock and control panel of the interior ventilation rate. The main construction material is rigid PVC of 5-7cm thickness (Detail 2010). The envelope is designed from concrete bricks and their thickness was assumed at 20cm. The services are full air-conditioning and there is no provision for natural ventilation.

The main activity which takes place inside the capsule is sleeping.

## 3.0 Methodology

Three methods were used in order to examine the potential biomimicry application inside the hive. The first two methods, which were applied in combination, were physical modeling and laboratory testing. The aim was to illustrate the airflow inside the hive in order to conclude the pattern of flow which succeeds in serving the required ventilation rate.

For the physical modeling, a transparent National Beehive brood box was constructed in 1:1 scale. The internal dimensions of the box were 365mm*425mm. It included 10 frames which spacing of 13-14mm between one another and 6mm from the external walls of the hive. The laboratory testing took place in the Adiabatic Boundary Layer Wind Tunnel in the Welsh School of Architecture. The mediums applied for the illustration of the flows were smoke (Draeger Air current smoke) and micro bubbles. The brood box was standing on a 150 mm high double-layered base: the bottom layer formed a wooden border 75mm thick but with a gap which allows air to enter the hive from the bottom and the top layer consists of two parallel rectangular blocks which allow the passage of air from the back. This structure allowed the upward flow of the air inside the hive but at the same time ensured that the pressure would not be excessive. The wind tunnel included two fans and the distance between the fans and the model was of 11-12m. The air speed inside the tunnel was 4.3m/s.

The third method was computer simulation for the thermal analysis using HTB2 (with building designs exported from Ecotect). HTB2 is a research tool which was developed in the Welsh School of Architecture and it simulates the energy and environmental performance of buildings. Hence, two models were created: the first illustrates a current capsule hotel and the second the capsule hotel including the biomimicry alterations. The input data considering the materials is illustrated in Table 1 and it is the same for both models. The analysis was carried out to evaluate the energy requirements and thermal comfort results for each scenario. The service was specified as a mixed mode system and the thermostat was arranged from 18-23ºC. However, there was a run in natural ventilation system so as to collect information on the internal air temperature of the capsules in the absence of any heating or cooling loads. Every capsule included a single occupant dressed in thermal resistance of clothing of 0.60clo (briefs: 0.04clo, shirt sleeveless: 0.06clo, sleepwear longsleeve, long pyjamas: 0.50), sleeping (metabolic rate: 40W according to Ecotect Software Library). There were three types of capsules: the first included a TV and alarm clock in use, the second a radio and an alarm clock and the third a light and an alarm clock. For the calculation of the internal gains inside the capsule, it was essential to be aware of the nameplate ratios of the appliances. The required values were collected by the U.S. Department of Energy website. So as to illustrate realistic conditions, the output of the appliances was concerned to be at 25% rate. As a result, the inputs for the three different cases of the internal gains were: 18.75W (TV&alarm), 15W (radio&alarm) and 5W (light and alarm). The infiltration rate was set as 10L/s per person. Both the base case and the altered model contained the same schedules in the occupants, infiltration and internal gains parts. The design plans of capsule hotels in Tokyo were not available; however, design plans for the similar 9H Hotel in Kioto were available and have been used in conjunction with climate data for Tokyo.

Table 1. The input data for the materials of both base case and altered case of the Capsule Hotel.

| | |
|---|---|
| Floor of the capsule | 75mm air gap, 50mm Polyvinyl Chloride Rigid, 200mm fibre Textile Organic Bonded |
| Ceiling of the capsule | 70mm Polyvinyl Chloride Rigid |
| Walls of the capsule | 30mm air gap, 50mm Polyvinyl Chloride Rigid |

The biomimicry alterations applied on the capsule hotels included rearrangements. The corridor in front of the capsules decreased its width from 1.60m to 1.00m so as to mimic the equivalent of the two bee-spaces in the human scale. Considering that an average arm to arm distance is of 0.50cm (Neufert 2000), the corridor was constructed in 1.00m width. Moreover, between the capsule room and the adjacent spaces there was provision for a corridor of 0.50m width (one bee-space in human scale) so as to resemble the air gap between the frames and the internal partition of the hive. The external wall of the capsule room was designed with 5 voids of 1.20m*1.80m dimensions so as to permit natural ventilation to enter the space. In 0.50m distance from the voids, there was a partition which mimics the internal boundary of the hive.

## 4.0 Results

### *4.1 Wind tunnel results*

Micro bubbles were introduced to the model through a cable which can be viewed in the left side of the snapshots of figure 3. A video camera was used to capture the position of the bubbles. Through an analysis of consecutive video frames separated by 0.04s (figure 3), it was possible to visualise the air flow patterns within the hive (figure 4).

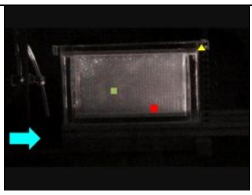
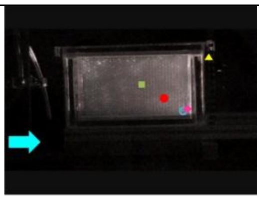
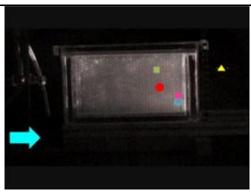
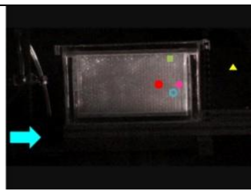
|  |  |  |  |
|---|---|---|---|
| 5.40 sec. | 5.44 sec. | 5.48 sec. | 5.52 sec. |

Figure 3. Consecutive video frames showing the brood box in the wind tunnel. The arrow in the bottom left illustrates the entering point inside the hive. The dots indicate the position of micro bubbles which were used to visualise the air flow patterns

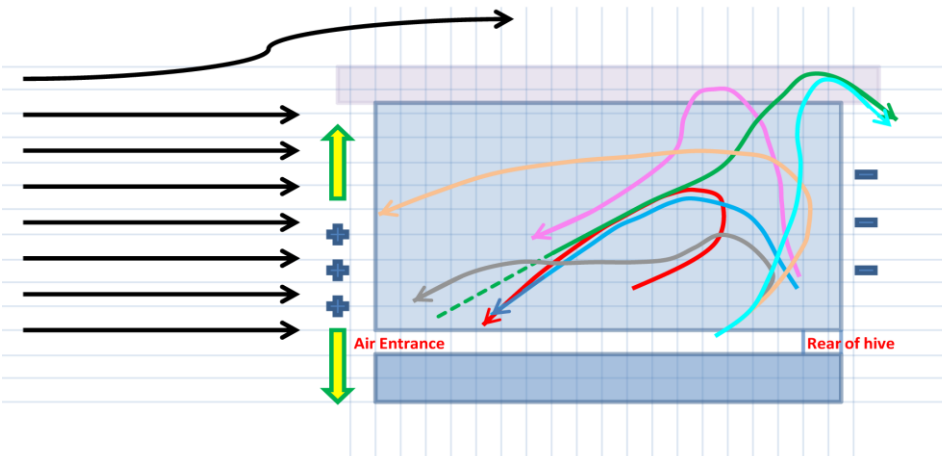



Figure 4. Air flow patterns inside the brood box. In black arrows the air flow from the wind tunnel fans is presented. In colored arrows, the air flows inside the hive are presented. Areas of high pressure are indicated with “+” and of low pressure with “-“.

Related to figure 4, there are two main flows inside the hive. The first (in red, blue, grey, pink, orange arrows of figure 4) enters from the bottom left (air entrance), reaches the right edge of the hive (rear of hive) and then flows upwards and curves towards the left side. The second (in green and cyan arrows of figure 4) also enters from the bottom left (air entrance), reaches the right side of the hive (rear of the hive) and flows upwards. Then, it continues rising until it reaches the covering and then it exits from the top right. For the first case, an average ratio between the internal to the external wind speed is approximately 1:6. In the second case the ratio is 1:8.5. This is calculated from the speed reduction of the micro bubbles when entering the hive.

It is evident that the air enters the hive from the entrance at the bottom front and is directed upwards before spreading throughout the interior of the hive. This allowed the majority of the frame area to be ventilated, but there may not be significant ventilation to the top corners of the hive.

*4.2 Thermal simulation*

The HTB2 analysis of a natural ventilation system for both the base case and the biomimicry alterations was focused on thermal comfort where the comfort zone was defined as 18-23$^{o}$C. The thermal simulation was carried out over a typical year. This time period was considered over 1 hour time periods resulting in 8760 results. For the base case 19.6% of the results were within the comfort zone; for the biomimicry altered module the result rose slightly to 20.8% of the results.

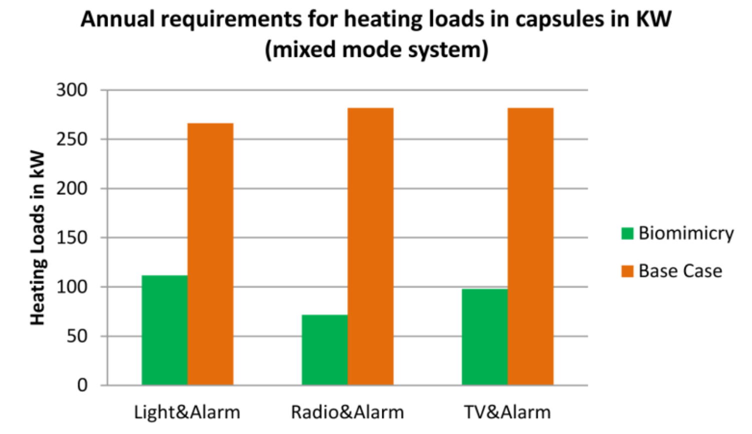



Figure 5.Capsule spaces of different internal gains and their annual heating loads requirements.

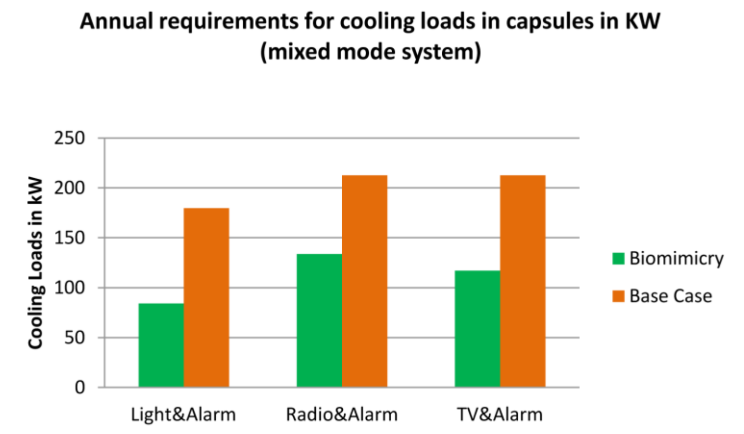



Figure 6. Capsule spaces of different internal gains and their annual cooling loads requirements.

As it is obvious from the graphs in figures 5 and 6, the biomimicry design of the single cells has lower annual heating and cooling loads requirements in comparison with the base case. In a mixed mode system analysis, the heating loads were 30-50% less than those required in the base case so as to provide comfort inside the capsule. As for the cooling loads (figure 6) the values were approximately halved after making the biomimicry alterations. The biomimicry alterations were found to have little impact on the internal temperature inside the capsule in a natural ventilation system analysis. The hottest day there was a $0.75^{o}C$ reduction compared to the base case, but on the coldest day of the year, there was an increase of $1.5^{o}C$ on the altered capsules.

## 5.0 Limitations

Although wind tunnels are designed for examining external air flows, this was the best option available to illustrate the flow pattern inside the hive. Moreover, during the examination the boundary layer was not considered. The applied wind speed was high in comparison to those usually experienced in a beehive, but was used to simulate the impact of bees fanning as well as wind flow through the hive.

## 6.0 Conclusion

The physical modeling of the air patterns indicates that there may be areas near the top corners of the hive which are not well ventilated. This situation is acceptable to bees who will simply minimize use of these areas and who can increase ventilation efforts (evaporative cooling and bee fanning) when the areas are occupied. Such an approach is less likely to be acceptable to hotel owners who need to maximize revenue from their investment, but could equally be tackled through selective use of mechanical ventilation when these areas are occupied.

The thermal performance of a biomimicry altered capsule is significantly better than the base case since it requires lower heating/cooling loads by approximately 50% while providing the same level of comfort. Moreover, the biomimicry altered model has a higher percentage of hours within the comfort zone, compared to the base case in a natural ventilation system analysis.

As a conclusion, it seems that biomimicry is able to give answers towards a more sustainable and holistic design approaches. Though it might not be as sufficient to cover all the needs of the contemporary human lifestyle, it can be a useful starting point for strategies and concepts, particularly where the inspirational species has similar needs to humans.

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